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The Denbigh Grits ; Wenlock Greywackes in Wales

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ABSTRACT

The petrography of the greywackes is described, with special emphasis on rock and mineral grains indicative of provenance. Sedimentary structures are discussed, and current directions based on flute cast measurements are recorded. The stratigraphy and palaeontology of the Denbigh Grits, and the facies of other parts of the Wenlock in the Welsh area are also considered. It is concluded that the greywackes were derived from an area of Pre-Cambrian rocks near south-west Wales and that they were transported along the axes of subsiding troughs by turbidity currents.

INTRODUCTION

THE Denbigh Grits are a series of greywackes, siltstones, and mudstones. They occur along the western margin of the Salopian outcrop in Wales in an almost continuous belt from Conway to Llanddewi-Ystradenny, a distance of about 70 miles (Text-fig. 1). Yet thick and persistent though they are, they form only a local facies of part of the Wenlock. The grits, so strongly developed in the west, die out eastwards and give way to shales. Such were the facts revealed by the early work of the Geological Survey in Wales (Ramsay, 1866, pp. 208 ff.).

The origin of the Denbigh Grits has been considered by several geologists in the past. Ramsay (loc. cit.) believed that their source lay mainly in the nearby Ordovician volcanic area of North Wales, an opinion also held by Boswell (1949, p. 9). Jones (1938, p. lxxxv, 1950, p. 330) also thought that they were derived from the west, but probably from a landmass lying in the present Irish Sea area. King (1928, p. 696) invoked contemporaneous folding in two directions to account for the distribution of these and other Lower Palaeozoic grits in Wales. They have generally been considered to have been deposited in " no great depth of water " (Jones, 1938, p. lxiv). King (loc. cit.) suggested that they were transported by long-shore currents, a possibility also recognized by Jones (1938, p. lxxxvii). Boswell believed that they formed as sandbanks in shallow water not far from the source of supply.

The greywacke facies, to which the Denbigh Grits clearly belong, has been much discussed in recent years. Bailey (1930, p. 88) argued that greywackes must be the product of resedimentation of unconsolidated sediments into deep water " beyond the reach of ordinary sand pushing currents ". Since Kuenen and Migliorini (1950) published their important paper on turbidity currents and graded bedding the resedimentation hypothesis has become accepted by an increasing number of geologists, with turbidity currents as the agents of redeposition.

The present study of the Denbigh Grits began in 1954 with detailed mapping of the northern part of the syncline west of Llanfyllin. Details of the geology of this area will be published later. It soon became apparent from a study of sedimentary structures that the greywackes had been transported by currents flowing from the south. In 1956 sedimentary structures were examined along the whole outcrop of the Denbigh Grits.

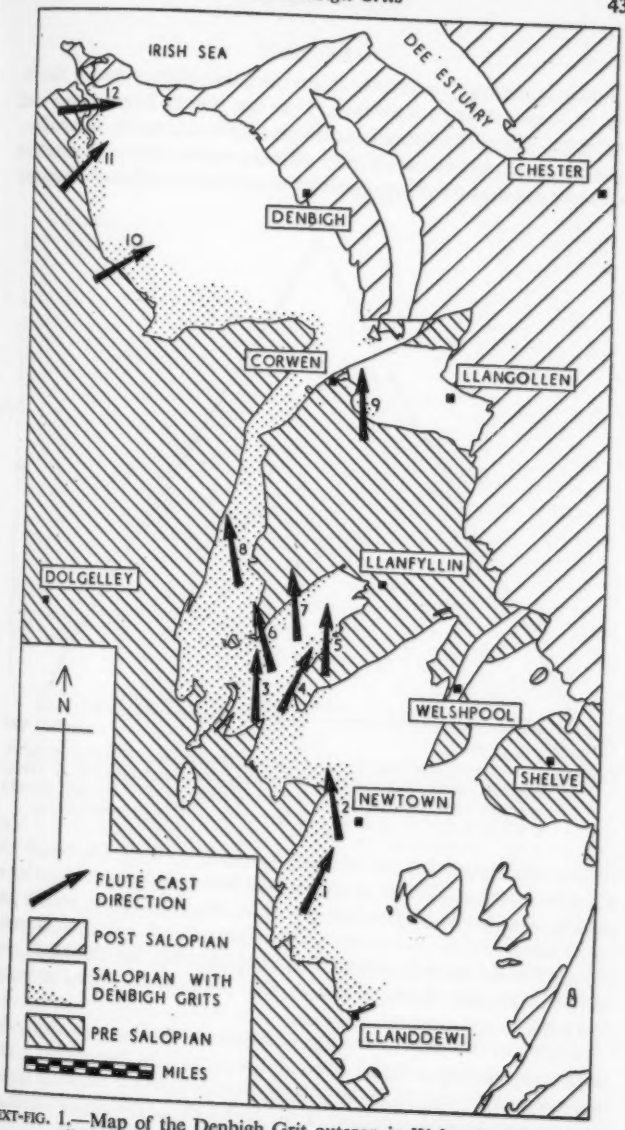
Stratigraphy

West of Llanfyllin the Denbigh Grits rest conformably on shales of the *C. murchisoni* zone. They come in at the same horizon at Tarannon (Wood, 1906, p. 653) and at Abbey Cwmhir (Roberts, 1929, p. 666). Near Conway they begin above the base of the *M. riccartonensis* zone (Elles, 1909, p. 187) and near Corwen they overlie shales of the *C. linnarssoni* zone (Wills and Smith, 1922, p. 203). Along the southern margin of the Denbigh Moors they seem to be conformable on the highest Valentian zone of *M. crenulatus* (Boswell, 1949, pp. 255, 358, 388). The Denbigh Grits are thus diachronous. Greywacke deposition began earliest in the central part of the area and later in the north-west and in the east.

The upper boundary of the Denbigh Grits is situated in the *C. rigidus* zone in the Denbigh Moors area (Boswell, 1949, p. 36) and at about the same horizon west of Llanfyllin.

The thickness of the Denbigh Grits over most of the outcrop is several thousand feet. They thin rapidly eastwards near Corwen and near Llanfyllin, and pass into a thin development of shales. Near Conway in the north-west the Denbigh Grits are also thin.

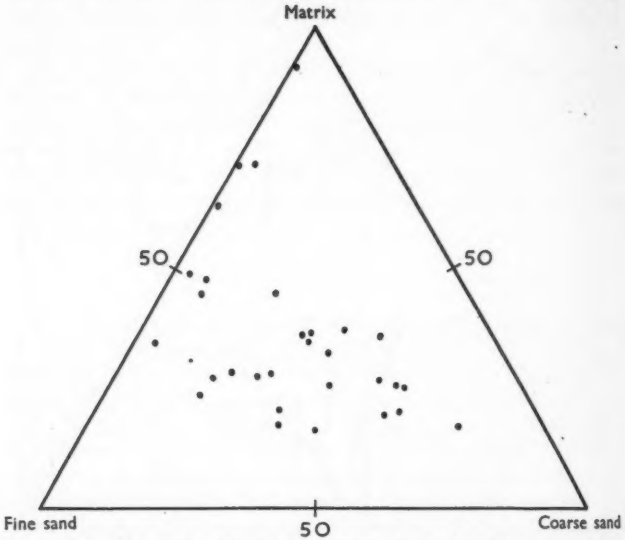
The Denbigh Grits were deposited in the subsiding Welsh basin and the area of greywacke deposition was one of relatively rapid subsidence. One margin of this rapidly subsiding area lay on a roughly north–south line passing east of Corwen and west of Llanfyllin. The Denbigh Grits thin rapidly towards this line and are replaced by shales to the east. Similarly, another margin must have been not far beyond Conway to the west or north.



TEXT-FIG. 1.—Map of the Denbigh Grit outcrop in Wales showing current directions based on flute cast measurements (Table I).

Fauna

Fossils are seldom common in the Denbigh Grits. Shelly fossils can be found at many localities. They are mostly fragmentary and scattered. The shelly fauna is dominated by brachiopods in numbers both of species and of individuals. Crinoid stem ossicles are common and there are also trilobites, gastropods, cephalopods, lamellibranchs,



Text-fig. 2.—Triangular diagram illustrating the sorting of the greywackes. Coarse sand, fine sand, and matrix are here defined as having greatest apparent diameters in thin section over 0·25 mm., between 0·05 mm. and 0·25 mm. and less than 0·05 mm. respectively.

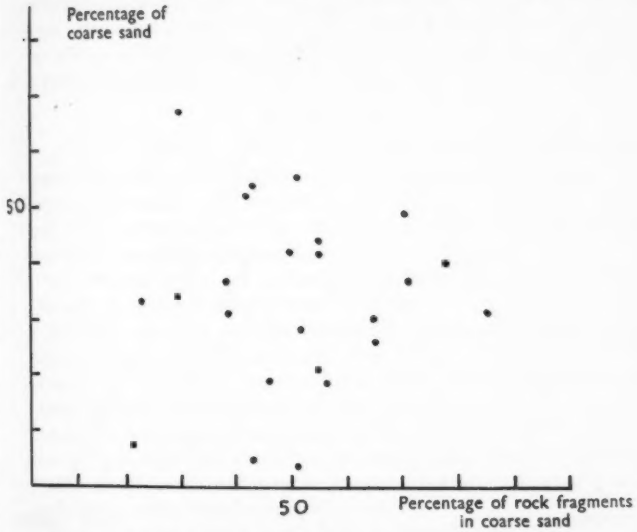
corals, and bryozoa. Lists of shelly fossils from several localities are given by Ramsay (1866, p. 212). Graptolites are uncommon and have usually been found on bedding planes in the greywackes, and in the interbedded shales. They are badly preserved and usually unidentifiable. Obscure plant fragments were first found in the Denbigh Grits by Hicks in 1874 (Hicks, 1881, p. 482) and can be found at many localities.

In spite of the relative scarcity of fossils in the Denbigh Grits, the total assemblage is a varied one. But it is perhaps doubtful if many of these organisms lived in the area of deposition of the Denbigh Grits. No conclusions have, therefore, been drawn about the environment of deposition of the Denbigh Grits, except that they are marine.

Petrography

This account is based on the study of over seventy thin sections of greywackes from all over the outcrop.

Texture.—The greywackes are poorly sorted mixtures of sand, silt, and clay grade materials. Grains over 2 mm. in diameter are rare. The coarse grains, mainly quartz, feldspar, and rock fragments are



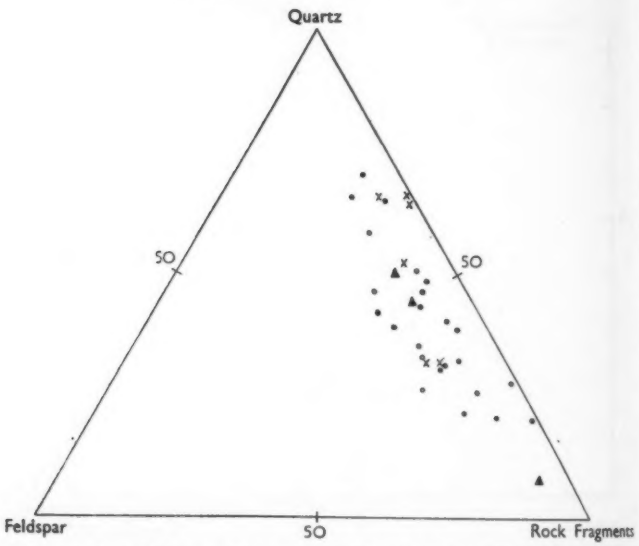
Text-fig. 3.—Plot showing the independence of grain size and the composition of the coarse sand fraction.

set in a matrix consisting largely of chlorite and sericite. There is no real distinction between grains and matrix, but it is convenient in the coarser greywackes to consider all grains below 0·05 mm. as matrix. The matrix is usually so altered that its original composition and texture are obscured. The sorting of these rocks is indicated in a triangular diagram (Text-fig. 2), which shows the proportions by volume of coarse sand, fine sand, and matrix in thirty specimens. The proportions were estimated in thin section, using a point counter, 500 points being counted in each section.

The roundness of sand grains was estimated in thin section with the aid of Pettijohn's chart (1949, p. 52). Five hundred and sixty-two quartz grains with greatest apparent diameter between 0·5 mm. and 1·0 mm. were examined in sixteen thin sections. The mean roundness

in every case was either high in the subangular class or low in the subrounded class. The totals in each class were :—

Angular	51
Subangular . . .	281
Subrounded . . .	213
Rounded	13
Well rounded . . .	4



TEXT-FIG. 4.—Triangular diagram illustrating the composition of the coarse sand fraction of the greywackes. Dots from the area mapped west of Llanfyllin ; circles from south of this area ; triangles from north of this area as far as Corwen ; crosses from the Denbigh Moors area.

The quartz grains commonly interdigitate with the matrix and in the finer grades this becomes so important a feature of the grain margin that an estimation of roundness is impossible. Examination of a few favourable slides, however, showed that smaller grains are generally more angular than larger grains in the same rock. Rock fragments tend to be better rounded than quartz grains of the same size.

The chief components of the greywackes are quartz, feldspar, rock fragments, and the chlorite and sericite of the matrix. Minor constituents are detrital sand grains of muscovite, biotite and chlorite, small detrital tourmalines and zircons, and secondary pyrite, hematite,

leucoxene, and calcite. These minor constituents seldom total more than 3 per cent by volume of the rock.

The relative proportions by volume of quartz, feldspar, and rock fragments in the coarse sand fraction are shown in the triangular diagram (Text-fig. 4). The proportions were estimated with a point counter, 100 to 500 points being counted in each slide. The considerable spread of points on this diagram has not been explained. The compositions of the coarse sand fraction is quite independent of the grain size of the sample (Text-fig. 3). The differences do not seem to be related to stratigraphy and there are no systematic differences between greywackes from different parts of the outcrop (Text-fig. 4).

Composition

(*a*) *Rock Fragments.*—The rock fragments occurring as grains in the greywackes represent a varied suite of igneous, metamorphic, and sedimentary rocks. Volcanic rocks are abundant, sedimentary rocks and low-grade metasediments are common, and intrusive igneous rocks occur sparingly in most slides.

The volcanic rocks are soda rhyolites, keratophyres, and spilites. The acid types are much the most abundant.

The soda rhyolites are microcrystalline quartzo-feldspathic rocks with very little chlorite, sericite, pyrite, hematite, and leucoxene. Some of the larger fragments have porphyritic albite or acid oligoclase and, rarely, quartz. The feldspars of the groundmass and of the non-porphyritic fragments, where determinable, are of the same composition as the feldspar phenocrysts. The rocks generally have a uniformly felsitic appearance. Some show irregular patches of coarser grains and others are traversed by quartz veinlets.

The keratophyres are more feldspathic than the soda rhyolites from which they are not sharply distinguished. Many of the keratophyres are free of quartz. Chlorite is the most common minor constituent. Some fragments have porphyritic albite or acid oligoclase. The plagioclase of the groundmass has a similar composition. The texture is commonly trachytic especially where quartz is absent or scarce.

The spilites are composed of laths of plagioclase in a chloritic matrix, usually with much leucoxene. The feldspars are often very weathered. The texture may be trachytic or the feldspars may show no obvious preferred orientation. Some fragments have porphyritic plagioclases which appear to be sodic. Some fragments are vesicular, the vesicles being filled with radiating chlorite. There are transitional types between the keratophyres and the spilites.

Pyroclastic rocks may also be present. Rocks consisting of angular grains of quartz and feldspar, and sometimes more rounded rhyolitic grains in a microfelsitic matrix, are probably ashes. The matrix may

be sericitic and is sometimes rich in leucoxene. Tuffs showing vitroclastic textures are absent.

The intrusive rocks are acid. Fragments of soda granite occur sparingly in most of the sections of coarse greywackes. They consist essentially of quartz and albite or acid oligoclase. No dark minerals are present in them. Granophyre and micropegmatite grains occur in most slides.

Metamorphic rocks, if slates are included in this category, form a significant part of the rock fragments in the greywackes. Rock types resulting from both regional and thermal metamorphism are represented. Quartz-muscovite schists are uncommon. Phyllites, slates, and cleaved muddy siltstones are more abundant. These rocks were cleaved before becoming sand grains in the greywackes. Spotted rocks are found in some of the sections. In these the spots are small, averaging about 0·1 mm. in diameter, and are seen between crossed nicols as dark patches in a brightly polarizing sericitic matrix. In ordinary light the spots may be greenish with fine chlorite, or yellow perhaps with pinite, and sometimes they show a slight concentration of minute leucoxene grains. The sericites of the matrix may have a parallel arrangement resulting perhaps from a cleavage in the rock prior to thermal metamorphism, or it may show decussate texture. Fragments of pelitic rocks without spots but showing marked decussate texture are probably also the products of thermal metamorphism, and some of the siliceous rocks look like hornfelsed siltstones.

The sedimentary rocks found as fragments in the greywackes include mudstones, siltstones, muddy siltstones, and fine greywackes. Many of these are probably contemporaneous.

(*b*) *Mineral Grains.*—Quartz is the chief mineral occurring in the greywackes. Many types of compound quartz grains occur. Some are vein quartz, others seem to be quartz schists, and some may be pieces of granite or quartzite. The simple quartz grains are usually clear, containing only minute inclusions scattered or in trails. Acicular inclusions are uncommon. Quartz grains containing inclusions of vermicular chlorite similar to those figured by Wallis (1927, Pl. LVIII, fig. 2) occur in many of the slides. Some of the grains with vermicular chlorite inclusions are compound.

The feldspars are chiefly plagioclase showing repeated albite twinning combined occasionally with pericline twinning. The refractive indices and extinction angles show that they are all albite or acid oligoclase. Chessboard albite (see Niggli, 1954, p. 251) is common. Orthoclase may be present but grains showing carlsbad twinning are very rare, and feldspars, apparently untwinned, may be sections of twinned plagioclase cut nearly parallel to (010) or they may be untwinned plagioclase. Perthite grains are not uncommon. Microcline is absent.

Muscovite in sand size detrital grains is generally not common in the greywackes but occurs abundantly on certain bedding planes. Biotite is uncommon and more often green than brown. In one slide a plate of biotite with quartz inclusions elongated in the cleavage probably came from a regionally metamorphosed source. Chlorite is a commoner detrital mineral than either of the micas. It occurs in plates or in aggregates of radiating or interleaved chlorite fibres. Some of these probably had an origin as chlorite-filled vesicles in lavas.

The tourmaline occurs in small prismatic grains or subangular fragments (0·05 to 0·18 mm. apparent length). It is pleochroic: Z = olive brown, olive green, occasionally blue-green or rich orange; X = colourless or pale yellow.

The zircons occur as small (0·05 to 0·2 mm. apparent length) grains varying from angular and subangular to rounded and well rounded.

Pyrite, hematite, ilmenite, and calcite are largely secondary. Of these pyrite is usually the most important, or hematite in weathered rocks. Occasionally calcite becomes a major constituent.

(*c*) *Conclusions.*—The poor sorting of the greywackes, resulting from the simultaneous deposition of coarse sand, fine sand, silt, and mud, is consistent with the turbidity current hypothesis. Detrital particles are transported by turbidity currents and are also an integral part of such currents. Sand deposited from clear water has interstitial water between the grains. Sand deposited from a turbidity current has an interstitial mixture of water and finer sediment. Since turbidity currents tend to develop a density stratification (Menard and Ludwick, 1951, p. 7) the pore spaces between the newly deposited sand grains may rapidly become choked with silt and mud from suspension.

The sand grains of the greywackes are poorly rounded, but the relationship between roundness and grain size is normal and the relatively more easily rounded rock fragments are better rounded than quartz grains of the same size. It can be concluded from this that the various constituents of the greywackes all had a similar, rather short abrasion history.

The source of the Denbigh Grits lay in a region in which volcanic rocks were predominant. Sedimentary rocks and granitic intrusions were also undergoing erosion. Regional metamorphism at least to biotite grade had affected some of the rocks and there was a little contact metamorphism, perhaps associated with the granites. The igneous rocks, soda rhyolites, keratophyres, spilites, and soda granites are all rich in soda.

The igneous rocks are characteristic of a petrological province rather than of a particular place or time. Igneous rocks, characterized by their richness in soda, and their sedimentary derivatives, occupy much of the Pre-Cambrian of Wales and the Borderland. The Mona

Complex of Anglesey (Greenly, 1919, p. 144), the Longmyndian of the Welsh Borderland (Thomas, 1918), and the Pebidian and Dimetian of south-west Wales (Thomas and Jones, 1912) are of this type. The Ordovician volcanic rocks outcropping in many parts of Wales are also largely, but by no means exclusively, sodic types.

The regional metamorphic rocks are probably Pre-Cambrian but they cannot be localized. The granitic rocks must also be Pre-Cambrian, since no Cambrian granites are known in this region and, even to-day, those doubtfully assigned to the Ordovician outcrop over quite insignificant areas.

The volcanic rocks are unlikely to be derived from the Ordovician of North Wales because of the absence of vitric tuffs which are so important in Snowdonia (D. Williams, 1930; H. Williams, 1927). Nor are they likely to be derived from the Ordovician soda rhyolites and keratophyres of South Wales as the albites in these rocks are commonly twinned on both Carlsbad and albite laws (Cox, 1915, p. 312; Thomas, 1911, p. 189), a feature not seen in rock fragments or feldspar grains in the Denbigh Grits. Thus, a Pre-Cambrian source seems likely for most of the material in the Denbigh Grits.

Chessboard albite is not a well-known mineral in British rocks. It occurs in soda granites, syenites, keratophyres, and other less common alkaline rocks. Its origin has been recently discussed by Exner (1949, pp. 251–260) and Battey (1955, pp. 105–7). The reference collection in the Geology Department at Liverpool University was searched. Thin sections of possible source rocks from all over the British Isles were examined and chessboard albite was found in only one (1698), a Dimetian granophyre from Porth Clais in Pembrokeshire. It was also found in thin sections of greywackes from the Pre-Cambrian South Stack Series of Anglesey and the Pre-Cambrian or Cambrian Bray Series of south-east Ireland in the collection of Professor R. M. Shackleton.

The complete absence of microcline, one of the more stable feldspars, from the Denbigh Grits is significant. Microcline occurs sparingly in the Penmynydd mica-schists of Anglesey (Greenly, 1919, p. 110). Microcline and orthoclase, sometimes showing Carlsbad twins, are present in the Coedana granite of Anglesey, and the albites of this granite are "often twinned on both planes with a microcline-like structure" (Greenly, 1919, p. 91). Microcline is present in the Pre-Cambrian granitic rocks of Shropshire (Bonney, 1879) and is abundant in the Malvernian granitic rocks, but is absent from the Dimetian granites of Pembrokeshire (Thomas and Jones, 1912, p. 387).

The petrological evidence is inconclusive but a largely Pre-Cambrian source for the Denbigh Grits is almost certain. Of the Pre-Cambrian rocks at present exposed in this region the Pebidian and Dimetian

groups of Pembrokeshire are the most likely source for the Denbigh Grits. A source area near south-west Wales is also supported by the evidence of current directions in the greywackes.

Sedimentary Structures

(*a*) *Internal Structures.*—Graded bedding is common in the greywackes of the Denbigh Grits, but is seldom obvious in the outcrop. Ungraded greywackes are also common. The lower margins of the greywacke units are always sharp and the upper margins usually so, though occasionally there is a complete gradation into the overlying mudstone. Usually, apart from the grading, the greywacke beds are uniform throughout, but sometimes this uniformity is broken by bands of coarser or finer material.

Lamination seems to be restricted to the finer greywackes and often appears at the top of a graded bed. Some beds are laminated throughout while in others the lamination is restricted to a band or bands within the bed. Surfaces covered with detrital micas are characteristic of many of the laminae in the greywackes. Sometimes the lamination is shown by thin films or lenses of a black opaque material resembling the anthracite described by Hicks (1882, p. 97).

Current bedding in units rarely exceeding an inch or two in thickness is common in the finest greywackes. Thin greywacke or siltstone beds may be current bedded throughout. Current bedding often follows above horizontal lamination at the top of a greywacke unit.

(*b*) *Bedding Plane Structures.*—Flute casts (Crowell, 1955) are common in the Denbigh Grits. The term flute cast has now replaced the earlier term lobate rill mark (Shrock, 1948) because of the unsuitable genetic implications of the latter.

Flute casts are more or less elongate structures occurring on the undersides of sandstone beds. They usually rise steeply at one end and at the other merge gradually with the bedding plane. They are very variable in shape and size. Rucklin (1938) distinguished and illustrated four types : a simple form (*einfache zapfen-wülste*), straight with the steep end rounded ; a corkscrew form (*korkzieher zapfen*), with the steep end rounded and twisted ; a flat form (*flachzapfen*), in low relief and with the steeper end acutely angular ; and a horseshoe form (*hufeisen-wülste*), which bifurcates behind the steep end. All these forms can be seen in the Denbigh Grits, as well as intermediate ones.

Flute casts sometimes occur individually, but are usually arranged in groups or covering large areas of bedding. They are not restricted, as implied by Crowell (1955, p. 1359), to striated bedding surfaces. They show a marked parallel orientation of their long axes and the steep ends point consistently in one direction.

Flute casts are the casts of flutings eroded in mud before the overlying sand was deposited. If the underlying mudstone is laminated, the laminae are cut by the flute cast. It is now well known that the long axes of the flute casts lie in the direction of the current responsible for their erosion and infilling, with the steep ends pointing upstream (Clarke, 1918, pls. 7–12 ; Rucklin, 1938, p. 110 ; Rich, 1950, p. 725 ; Kuenen, 1953, p. 1051). This can be confirmed at several localities in the Denbigh Grits. In the large quarries (070910) [1] 2½ miles west of Newtown, flute casts and current ripple marks are both abundant and indicate the same current direction. Also in on the north and south slopes of Boncyn Celyn (040183), 6 miles west of Llanfyllin, flute casts are found at the base of thin current bedded units in which the foreset beds dip in the direction of the current indicated by the flute casts.

Groove casts (Shrock, 1948) are rather less common than flute casts in the Denbigh Grits. They are the casts of grooves in mud cut prior to the deposition of the overlying sand. Dzulynski and Radonski (1955) demonstrated that groove casts in the Carpathian flysch were cut by angular shale fragments dragged along the sea floor, probably by turbidity currents. A similar explanation seems likely for the groove casts occurring in the Denbigh Grits. Groove casts indicate the trend of the current, but do not show which way it flowed.

Load casts (Kuenen, 1953), the flow casts of Shrock (1948) but not of Prentice (1956), have also been found in the Denbigh Grits. They yield no information about current directions.

Current ripple marks in the Denbigh Grits occur in fine sandstone and siltstone at the tops of greywacke beds. They are usually rather large, up to a foot or so in wavelength, and may be complex resembling the linguoid current ripples of Bucher (1919, p. 164) and some of the forms described as current mark by Kindle (1917, p. 36). Such ripples are probably the result of irregular or troubled currents (Kindle, 1917, p. 37) and are common on tidal flats and in other environments where the water level undergoes a rapid change leading to a complete exposure (Bucher, loc. cit.).

Aligned graptolites are occasionally found in the Denbigh Grits. In the large quarries west of Newtown there are beds of laminated greywacke with flute casts at the base and current ripple marks at the top. A few bedding planes in some of these beds are covered with large detrital micas and aligned graptolites. The graptolites lie with their lengths parallel to the current direction.

(*c*) *Conclusions*—Graded bedding in greywackes with interbedded mudstones, combined with evidence of the action of strong bottom currents, is characteristic of the Denbigh Grits. Some, perhaps all,

[1] Figures in brackets are National Grid References.

of the sedimentary structures described may occur in continental strata deposited by sediment-laden flood waters (Cummins, 1957) ; but fresh-water floods are rapidly dissipated on entering the sea unless they are sufficiently dense to flow along the bottom as turbidity currents. In a marine environment, turbidity currents would seem to be the only agents able to produce the combination of features found in the Denbigh Grits.

The features of the current ripple marks need further explanation. The fluid responsible for the formation of these current ripple marks was a turbidity current. The character of the ripple marks, therefore, depends on the properties and behaviour of the turbidity current and is unrelated to the depth of the overlying sea water.

Current Directions

During the detailed mapping of the area west of Llanfyllin the trend of sedimentary structures was measured wherever they were found. All accessible sedimentary structures were measured, but not more than one measurement was made on the same bedding plane in any exposure. Sixty-seven measurements of flute cast directions were recorded and these show that the currents in this area flowed consistently northwards (Text-fig. 5*a*). Five measurements were made on current ripple marks which also indicate northward flowing currents. Seventeen measurements were made on groove casts and ten on other linear structures which give a trend but not a sense of movement of the currents. The maximum of these measurements is much less clearly defined than that of the flute cast directions.

Flute cast directions were then measured in other parts of the Denbigh Grit outcrop. Considerable search had to be made for exposures where flute casts could be observed. Much of the country is badly exposed ; hillside exposures are usually so weathered that sedimentary structures are obscured ; in gently dipping rocks the bottoms are rarely visible ; and, in any case, many bedding planes were originally devoid of sedimentary structures. The most suitable types of exposures are of steeply dipping beds in stream sections or quarries, or any beds in crags or steep hillsides where erosion is rapid. Thus, random sampling of exposures was soon found to be impracticable. However, in view of the constancy of flute cast directions in the area mapped (Text-fig. 5*a*), it is believed that the few measurements made in other parts of the outcrop do give a true indication of the current directions.

Flute cast directions over the whole of the Denbigh Grit outcrops are shown on the map (Text-fig. 1). For convenience of representation on this map the outcrop has been divided into twelve areas in which measurements were made. Each area consists of one or more

neighbouring localities. The localities may be hillsides, stream sections, quarries, or other compact groups of exposures. The results are summarized in Table I.

TABLE I.—LOCATION OF AREAS AND LOCALITIES AND NUMBER OF READINGS IN EACH AREA

Weighted mean directions in each area are given as bearings from true north. The means are weighted according to the number of readings in each locality.

Area.	*Description.*	*No. of Localities.*	*No. of Readings.*	*Weighted Mean.*
1	Stream sections (038827, 036823, 053852)	3	7	23°
2	Quarries (070910, 069956)	2	9	348°
3	Stream section (985075)	1	5	358°
4	Moel Bentyrch (0509) stream section (032072)	2	21	24°
5	Dolanog (0612) area, north of River Banwy	8	13	360°
6	Afon Twrch (9912), stream section (003148)	2	11	343°
7	Yr Allt Boeth (0216), Boncyn Celyn (0318) Crag (075209), Melyn-y-Graig (032179)	5	27	354°
8	Stream sections (957257, 963224)	2	6	349°
9	Corwen Slate mine (108423)	1	5	358°
10	Quarry (820578)	1	1	62°
11	Cliffs (782694)	1	7	44°
12	Benarth Shore (7877)	1	2	82°

It can be seen from the map (Text-fig. 1) and from Table I that in areas 1 to 9 along the north–south belt from Corwen to Llanddewi the currents flowed consistently towards the north, and that in areas 10 to 12, on the western side of the Denbigh Moors, they flowed towards the east or north-east. The distribution of flute cast directions measured in areas 1 to 9, excluding the area west of Llanfyllin which was mapped in detail, is shown on Text-fig. 5*b*. Those measured in areas 10 to 12 are shown in Text-fig. 5*c*. Very few measurements were possible in the Denbigh Moors area as the country is most unsuitably exposed. A comparison of Text-fig. 5*c* with Text-figs. 5*a* and 5*b* suggests that the difference in current direction between the Denbigh Moors area and the rest of the Denbigh Grit outcrop is real and is not an illusion resulting from inadequate sampling.

Important features of the current directions in the Denbigh Grits are their relation to other aspects of this series. Along the north–south belt, from Corwen to Llanddewi, the currents flowed parallel to the eastern margin of an area of subsidence (see p. 434), a line along which the grits thin rapidly eastwards and pass into shales. Also in both the north–south belt and the Denbigh Moors area the currents flowed roughly parallel to the main tectonic trend. If these relation-

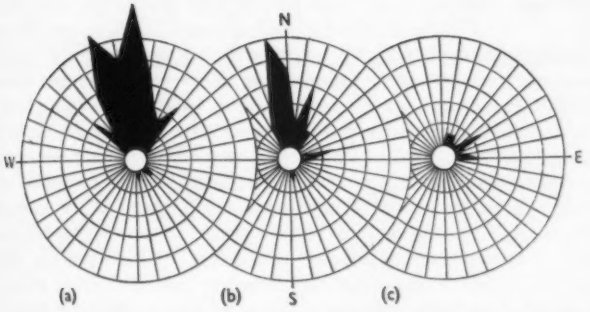
ships held in other parts of the Denbigh Grits now no longer exposed, the following conclusions may be reached :—

(1) The facies change from greywacke to shale continued south-westwards from Llanddewi into Pembrokeshire.

(2) The currents flowing northwards from Llanddewi to Corwen originated south-west of Llanddewi.

(3) A facies change from greywacke to shale lies north of Corwen and runs in an easterly or north-easterly direction.

(4) The currents flowed along the axes of tectonically controlled troughs now represented by the Central Wales and the Snowdon Synclinoria, separated by a submarine ridge, now the Merioneth Dome.

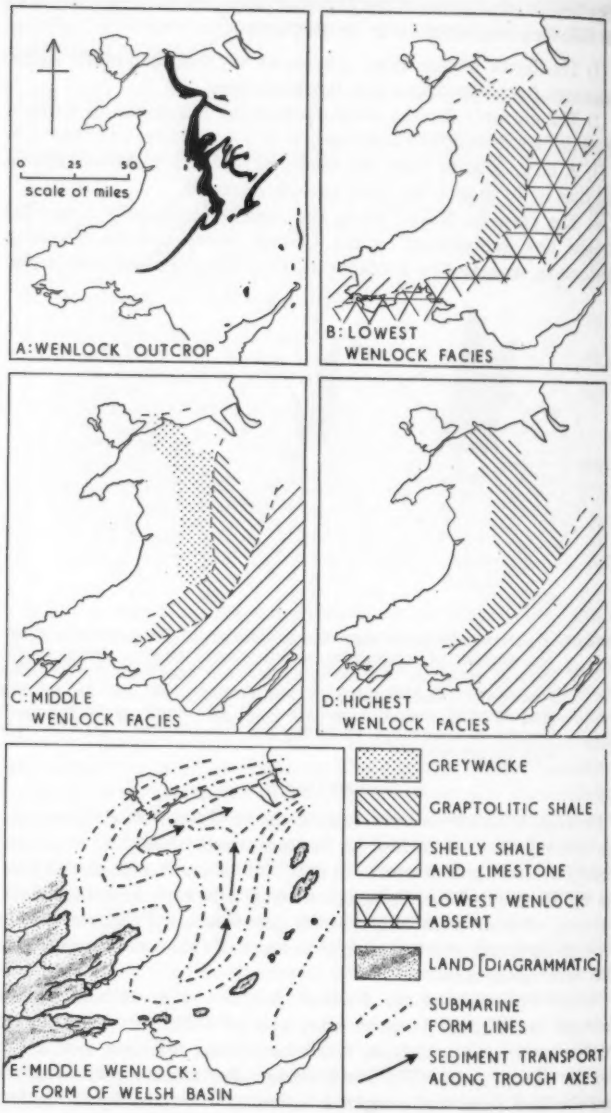


TEXT-FIG. 5.—Rose diagrams showing distribution of flute cast directions. The number of readings in each 10-degree class is shown by the distance from the innermost circle, each concentric circle representing two readings (cf. West and Donner, 1955, p. 78). (*a*) The area mapped west of Llanfyllin ; (*b*) The north–south belt from Corwen to Llanddewi, excluding the area mapped ; (*c*) The Denbigh Moors area.

DISCUSSION

Detailed conclusions have been given at the end of each section. An attempt is made below to fit these conclusions into a general history of the Wenlock period in the Welsh area. Facies maps (Text-fig. 6*b*, *c*, *d*) based on the work of many geologists have been used. Features of other areas of greywacke deposition, and the relationship between structure and topography in areas of recent movements have also been considered.

At the beginning of the Wenlock period a ridge of land passing through the Church Stretton area, east of Builth, and into south Pembrokeshire, separated the Welsh basin from the open shelf sea to the east (Text-fig. 6*b*). The Welsh basin subsided during the Wenlock and the land ridge was completely submerged long before the end of


0 25 50
scale of miles
A: WENLOCK OUTCROP
B: LOWEST WENLOCK FACIES
C: MIDDLE WENLOCK FACIES
D: HIGHEST WENLOCK FACIES
E: MIDDLE WENLOCK: FORM OF WELSH BASIN
GREYWACKE
GRAPTOLITIC SHALE
SHELLY SHALE AND LIMESTONE
LOWEST WENLOCK ABSENT
LAND [DIAGRAMMATIC]
SUBMARINE FORM LINES
SEDIMENT TRANSPORT ALONG TROUGH AXES

the period, but probably remained as an important submarine feature into Lower Ludlow times. While the Welsh basin was subsiding, land to the south-west was rising. These movements took place along well-defined tectonic axes, the trends of which were reflected in the topography of the emergent land in the south-west and in the form of the Welsh basin (Text-fig. 6*e*).

Erosion was rapid in the newly uplifted land and much sediment reached the sea and was temporarily deposited at the south-western end of the basin. At intervals this sediment was carried into the basin by turbidity currents flowing down the axes of the troughs. These turbidity currents were probably set off by earthquakes associated with the movements. The transport of sediment in the trough was dominantly parallel to the tectonic trend and probably very little material was supplied from the sides (cf. Kuenen, 1957).

The movements had already started at the beginning of the Wenlock period and greywacke was being deposited in the centre of the basin (Text-fig. 6*b*). From the *M. riccartonensis* zone, right through the Middle Wenlock, up into the *C. rigidus* zone the movements continued and greywacke was deposited over a large area of the basin (Text-fig. 6*c*). The basin was probably divided into two troughs, was separated from the open sea to the east by a submerged, or partly submerged, ridge, and had a narrow outlet to the north-east (Text-fig. 6*e*). Towards the close of the Wenlock period the movements became less intense. Erosion of the land was less rapid and less sediment reached the sea. Though turbidity current deposition certainly continued, no greywackes were deposited in the basin during the *C. lundgreni* zone (Text-fig. 6*d*).

Acknowledgments

This research was carried out during the tenure of an Isaac Roberts postgraduate studentship in the University of Liverpool. The author wishes to express his thanks to Professor R. M. Shackleton, Mr. R. G. C. Bathurst, and Dr. B. E. Leake for helpful discussion and criticism.

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Text-fig. 6.—Maps of Wales showing outcrop of Wenlock rocks, facies at different times during the Wenlock period and the palaeogeography during the Middle Wenlock, based on the study of the Denbigh Grits.

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An Outline of the Structure of the Galway Granite

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Abstract

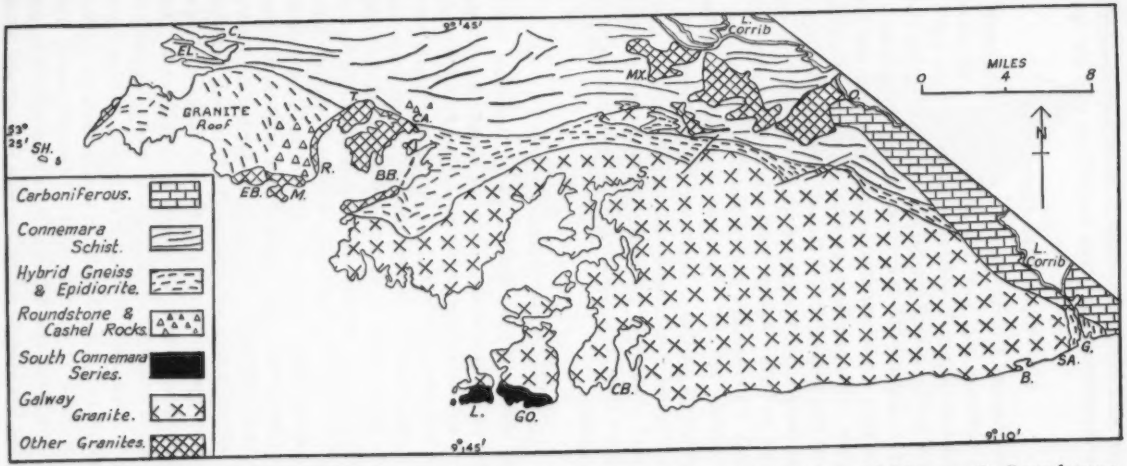
Remapping of parts of the Galway granite has shown that over most of its outcrop it is a homogeneous adamellite. A steeply dipping belt of basic rocks borders the intrusion on the north where there is a reaction zone between adamellite and basic rock. A similar but gently dipping belt of basic rocks overlies the granite to the west. In the south, where there is no reaction zone, the granite intrudes and hornfelses a group of pillow lavas, greywackes, and conglomerates. The structural features of the northern border indicate that the granite has been emplaced as a diapir and radial fractures in the north-east border further indicate that the granite and its basic envelope moved upward and outward together into the Connemara schists.

Introduction

THE Galway granite outcrops over a roughly rectangular area approximately 40 miles by 10 miles on the northern side of Galway Bay (Text-fig. 1). On the east the granite is overlain unconformably by Carboniferous limestone and to the south and west it extends under the sea so that only the northern border is well exposed. A short length of the contact and a small area of country rock are exposed south of the mainland on Lettermullen and Gorumna islands. The geology of these islands has been described by Duncan McKie and the writer (McKie and Burke, 1955). The age of the granite is also discussed in that paper.

The granite was described in sheet memoirs of the Geological Survey of Ireland published between 1869 and 1878 (Kinahan, 1869; Kinahan and others, 1870, 1871, 1878). Kinahan (1869, p. 16) considered that there was a passage across the contact from porphyritic granite through schistose granite into mica-schist and inferred that the granite was formed *in situ* by the melting down of schist. Callaway (1887) described agmatites (for which he coined the term " diglomerates ") from various places on the margin of the granite. He rejected Kinahan's interpretation of the border structures because the granite in the agmatites intrudes the country rock. Grenville Cole (1916) described some rocks of the type called hybrid gneisses in this paper from boulders at Barna on the coast west of Galway.

Wager (1932) in a paper on the basic rocks west of the Galway granite described three of the smaller intrusions which occur in that area. Murphy's (1952) observations of gravity extend over the whole of the granite. The present writer has mapped an area which covers the northern border from the Carboniferous unconformity to longitude



TEXT-FIG. 1.—The Galway granite. SH, Slyne Head; EL, Errislannan; C, Clifden; EB, Errisbeg; M, Murvey; R, Roundstone; T, Toombeola; CA, Cashel; BB, Bertraghboy Bay; L, Lettermullen; GO, Gorumna; CB, Cashla Bay; MX, Maam Cross; S, Screeb; O, Oughterard; B, Barna; G, Galway; SA, Salthill.

9° 34′ W., and with McKie the whole of the exposed southern border. Extensive reconnaisances have been carried out over the rest of the granite.

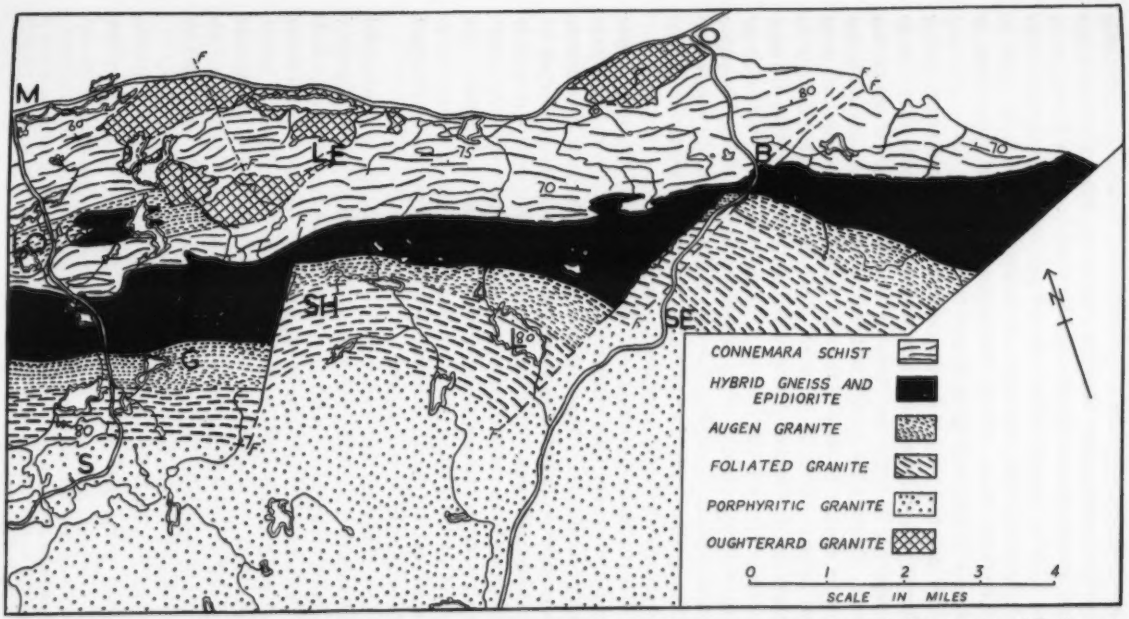
The Porphyritic Adamellite

Most of the exposed Galway granite is porphyritic adamellite other facies being common only near the margin of the intrusion. The adamellite consists of potash feldspar phenocrysts, from 2 to 5 cm. in length, set in a groundmass of quartz, plagioclase (oligoclase-andesine), potash feldspar, and biotite; hornblende is sometimes present but is nowhere abundant; a wide variety of accessory minerals and alteration products occurs. Although there are local variations in the abundance of phenocrysts the adamellite is a broadly homogeneous rock except for a general decrease in the size of its phenocrysts from north to south and east to west. Aplites, pegmatites, and quartz-porphyries all occur within the adamellite being especially abundant close to the margins. Xenoliths are not conspicuous being represented by rare irregular biotite-rich patches. There are many shatter belts in the granite and retrograde mineralogical changes are common both along these belts and elsewhere; plagioclase is often saussuritized and sericitized, biotite chloritized, potash feldspar microclinized, and large quartzes granulated.

The North-eastern Border

The Galway granite is separated from the Connemara Schists on its northern border by basic rocks. In the north-east there is a gradual transition from the adamellite outwards into basic rock (Text-fig. 2). This transition is the result of both chemical and mechanical processes. At the same time as granite reacted chemically with basic rocks to produce more mafic facies basic xenoliths were mechanically incorporated in granite and granite veins were intruded into basic rocks. The two processes played complementary roles in the production of the rocks of the transition zone; xenoliths of basic rock caught up mechanically in the granite and veins of granite mechanically intruded into the basic rock both reacted chemically to form hybrid rocks.

Within the transition zone four main facies have been distinguished and four zones mapped in each of which one facies predominates. The boundary between granite and country rocks has been mapped between the second and third of these zones. The two granitic facies in the transition zone are a foliated granite and an augen granite. At approximately 1 mile from the edge of the intrusion the porphyritic adamellite gives place to a rock in which tabular potash feldspar phenocrysts are arranged with their (010) faces parallel to the granite edge. This rock, the foliated granite, is well seen on the shores of



TEXT-FIG. 2.—The north-east of the Galway granite. M, Maam Cross; G, Glentrasna; S, Screeb; SH, Shannawon; LE, Leam; O, Oughterard; B, Bunnagippaun; SE, Seecon; LO, Loughaunfree; L, Lettercraffroe.

Lettercraffroe Lough and on the summit of Seecon. It is more mafic and less homogeneous than the porphyritic adamellite having both dark hornblendic and light feldspathic patches. In the foliated granite the euhedral potash feldspar phenocrysts may be larger than in the porphyritic granite reaching a maximum length of 8 cm. Near the edge of this zone, close to the augen granite, flat quartz lenses lie between the layers of feldspar crystals.

The augen granite is characterized by lens-shaped potash feldspar phenocrysts and by quartz layers 2 to 3 mm. thick formed by the coalescence of lenses like those in the adjacent part of the previous zone. Towards the margin of the zone the potash feldspars become smaller and the layering so fine that there may be ten or more quartz and feldspar layers to the inch. The foliation of the margin of the granite is a flow feature produced during its diapiric uprise. The augen structure of the feldspars and the closeness of the foliation in the outer zone are evidence of the greater intensity of the movement close to the edge of the granite. The boundaries between the various zones at the granite margin are nowhere abrupt and generally involve a passage by alternation over many yards.

The two facies distinguished in the outer part of the transition zone have been termed epidiorites and hybrid gneiss. Both facies may be further subdivided. The epidiorites are mostly massive hornblende-plagioclase rocks but more mafic types occur including diopside and hypersthene-bearing rocks and tremolite serpentines. Nearly all the epidiorites have suffered retrograde metamorphism toward low-grade assemblages containing albite, epidote, tremolite, and chlorite.[1] The hybrid gneiss is most often a foliated quartz-andesine-biotite-hornblende rock but potash feldspar is common and the relative abundance of the minerals is very variable.

The epidiorites are interpreted as isochemically metamorphosed basic rocks and the hybrid gneisses are believed to be products of reaction between the potash deficient basic rocks and the more potassic Galway granite; less altered rocks contain biotite with hornblende and more altered rocks potash feldspar and biotite with or without hornblende. Hybrid gneiss is commoner than epidiorite, the latter becoming more abundant away from the granite. There are no outcrops of epidiorite more than a few square yards in area which are not broken up into agmatites by hybrid gneiss or augen granite.

The occurrence of agmatized epidiorite at many places within the hybrid gneiss and the sporadic distribution of rocks with potash

[1] Retrograde changes are widespread in the crystalline rocks in this part of Connemara; they are associated with late faults and fractures. Comparable assemblages have been produced by progressive regional metamorphism in the Silurian greywackes to the north. The changes are therefore probably of Caledonian age.

feldspar within the hybrid gneiss zone are probably due to movements within the granite envelope during its diapiric rise. Such movements would account for the frequent juxtaposition of rocks representing different zones and types of granite-basic rock reaction.

The Connemara schists outside the reaction zone consist of sillimanite gneisses, andalusite gneisses, semipelitic gneisses, quartzites, amphibolites, and marbles. The boundary between the basic rocks and the Connemara schists is intricately folded and each contains tectonically isolated fragments of the other. Except around Loughaunfree (see below) there is little evidence of the entry of the Galway granite into the metasediments; the basic rocks seem to have proved an effective barrier to injection. The main effect of the intrusion of the Galway granite into the Connemara schists seems to have been rotation of the foliation into a steep attitude parallel to the granite margin.

As the two end members of the transition series, the adamellite and the epidiorite, are themselves unfoliated the foliation in the transition zone must have been mechanically produced. The planar structures in many injection gneisses are probably, at least in part, due to flow but it is only in rare cases that the origin of a foliation can be demonstrated, as in this case, to be entirely mechanical. The north-eastern border of the Galway granite provides an example of the type of flow structure at a granite margin described by Cloos and others, though the extent of reaction suggests that the Galway granite is more deepseated and closer to thermal equilibrium with its country rocks than is usual in granites showing these structures.

The North-western Border

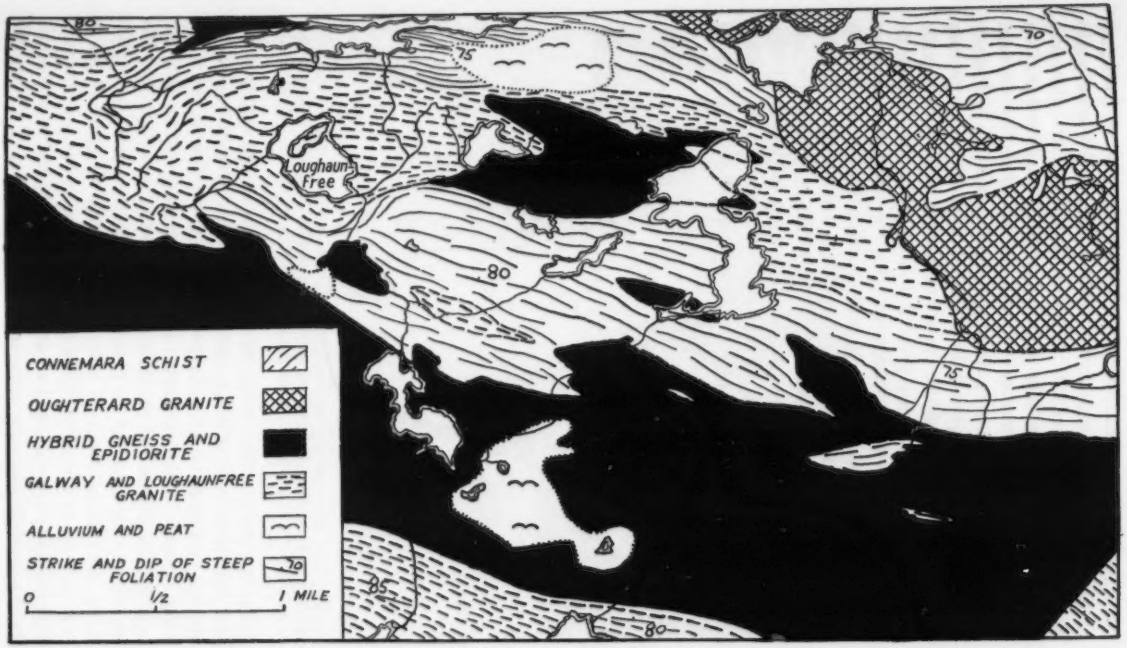
The reaction zone extends westward along the northern border and bounds the Galway granite from the Carboniferous unconformity to Bertraghboy Bay. The granite contact dips steeply and is concordant with the foliation of the gneisses in the reaction zone as far as 9° 38′ W. Beyond that longitude the present level of exposure is closer to the gently inclined roof of the granite; as a result the dip of the contact becomes rapidly less and its strike swings to the south-west to narrow the granite outcrop. In this area dips in the reaction zone are low and the granite is locally transgressive. The foliated and augen granites are not exposed and the main adamellite is less homogeneous. West of Bertraghboy Bay rocks of the reaction zone outcrop over a wide area although the Galway granite is not exposed. It seems probable, however, that the rocks exposed in the country south and west of a line from Errislannan to Toombeola overlie a westward extension of the granite. Hybrid gneiss of variable strike with generally low dips outcrops over much of this area and within

it there are numerous bodies of basic rock some of which are only slightly metamorphosed. The largest of these, at Roundstone, has been described by Wager (1932). It contains peridotites, picrites, gabbros, and other basic rocks as well as a quartz-diorite gneiss which Wager regarded as an early orogenic trondhjemitic intrusion into the basic rocks. This rock is very similar to the hybrid gneiss of this paper which is the product of reaction between the adamellitic facies of the Galway granite and the basic rocks. This origin of the hybrid gneiss could hardly be inferred from the evidence in the Roundstone area where the granite is not exposed. The Roundstone rocks are rich in hornblende and contain coronites. Wager ascribed these features to a high water content in the basic magma from which the rocks originally crystallized. The position of the basic rocks in what appears to be the roof of the Galway granite suggests that these changes may be the results of metamorphism associated with the granite.

Although the Galway granite proper does not reappear west of Bertraghboy Bay there are four intrusions of cross-cutting granite into the hybrid gneiss of the roof area. Wager has described three of these, the Roundstone, Errisbeg, and Murvey granites. The Roundstone granite is a biotite-hornblende-adamellite, non-porphyritic, but otherwise like the adamellite of the Galway granite. It has a roughly circular outcrop about 4½ miles in diameter. The Errisbeg townland granite is a biotite-adamellite with perthite phenocrysts and the Murvey granite is a quartz-albite-perthite-rock with molybdenite-bearing greisens. These granites are like the Galway granite but show later and higher level features in structure and composition. The fourth granite in the roof zone outcrops on the extreme west coast near Slyne Head. Additional evidence of the westward extension of the granite is provided by the observations of gravity made by Murphy (1952). He points out that the extension of an area of low anomaly from the Galway granite towards Clifden suggests the underground extension of the granite in that direction.

The Loughaunfree Granite

One large body of Galway granite has been found outside the enveloping basic rocks. This is the concordant augen granite of Loughaunfree. Elsewhere the basic rocks seem to have proved an effective barrier to the emplacement of Galway granite in the Connemara schists. The Loughaunfree mass (Text-fig. 3) is exposed over an area about 2½ miles from east to west by 1 mile from north to south. The augen granite is like that of the main outcrop with the usual inhomogeneities and xenoliths. These features are well displayed along the road from Maam Cross to Screeb. The planar



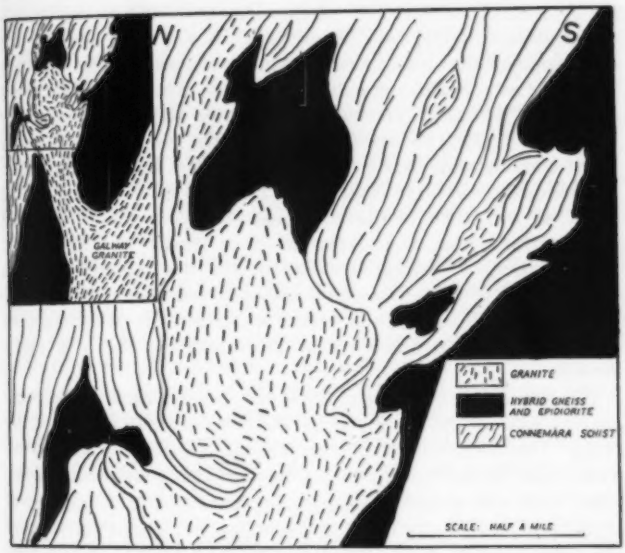
TEXT-FIG. 3.—The Loughaunfree granite.

structures in the granite are parallel to those in the adjacent Connemara Schists. Linear structures have not been distinguished in the granite or the hybrid gneiss but fifty records of fold axis orientations have been obtained from xenoliths of pelitic gneiss in the granite and from pelites in the country rocks around the Loughaunfree intrusion. Text-fig. 4 is an equal area projection of the recorded fold axes in and around the granite and Text-fig. 5 is a profile drawn at right-angles to the sheaf of fold axes in the projection. Although the profile is based on data from the pelite it is believed to be valid for the granitic and other rocks associated with the pelite but themselves lacking macroscopic linear structures because the planar structures in these rocks are known to be concordant with those in the pelites and because the pelite outcrops are well distributed over the quite small area plotted on the profile. The inset in Text-fig. 5 is an uncontrolled cross-section on which the position of the profile is shown. Owing to changes in axial plunge it is not possible to extend the controlled section over a larger area.

TEXT-FIG. 4.—Lower hemisphere projection of fifty fold axes from pelites in and around the Loughaunfree granite. (Contours 28, 8 and 2 per cent.)

As the uncontrolled section shows the Loughaunfree granite pierces the epidiorite and hybrid gneiss envelope that bounds the Galway granite and rises up into the pelite. The south side of the profile shows 2 miles of the envelope. The intricate nature of the boundary against the pelites and an isolated fragment of basic rock are also shown. In the centre of the profile the granite rises through the pelite for a distance of about 1½ miles and is capped at its upper end by a large fragment of hybrid gneiss with epidiorite. The appearance of this fragment above the granite on the profile suggests that it has been raised bodily through the pelite by the granite. North of this cap rock

there is an arm of granite which passes out of the area of constant axial plunge. The northern contact of the granite is straight. Basic rocks occur along it only as a few xenoliths. The lower end of the profile is remarkable for two "jaws" of pelite which protrude into the granite, the appearance of the "jaws" suggests that the granite may have been fed through a restricted opening and have swelled up above the constriction like an inflating balloon. North of the constriction there is a body of epidiorite with hybrid gneiss isolated in the



TEXT-FIG. 5.—Profile through the Loughaunfree granite with inset section showing the position of the body in relation to the main Galway granite.

pelite; these bodies are not uncommon in the Connemara schist, some are tectonically isolated fragments of the main basic mass and others are discrete intrusions in the schist. This particular body is probably one of the former. At its western end the Loughaunfree granite is bounded on both sides by hybrid gneiss which forms part of the main granite wall.

MARGINAL FRACTURES

There are vertical radial fractures at two places on the northern border of the Galway granite. These fractures developed late in the

history of the intrusion at a time when the granite was more rigid than the basic rock border. In each case the outward rotational movement of the broken granite has been accommodated by movement of the basic gneisses in such a way as to retain the smooth outline of the Galway granite and its envelope (Text-fig. 2).

The Shannawon fault, the more westerly of the two fractures, occupies a 100 yard wide depression in the hills 1 mile east of Glentrasna where it throws the augen granite-hybrid-gneiss junction a horizontal distance of 1 mile. The basic rock outcrop is 1½ miles wide on the west of the fault and ½ mile wide on the east so that there is no displacement on the northern side of the basic rocks. The Bunnagippaun fault about 4 miles further east consists of two fractures which throw the augen granite-hybrid gneiss boundary a horizontal distance of 2½ miles. The larger fault of this pair has a throw over 2 miles long. The two faults together shift the basic rock-Connemara schist boundary just over ½ mile. The faults are not well exposed in the metasediments; the Shannawon fault can be recognized by its effect on the strike of the rocks east of Leam summit and the Bunnagippaun fault is also marked by a change of strike in the metasediments. Although the line of the Bunnagippaun fault is nowhere well exposed it can be localized between Seecon and Lettercraffroe and at Bunnagippaun 2 miles to the east. Its straight outcrop over a 400 ft. drop between these points suggests that it is nearly vertical.

The dips of the steep foliations in the reaction zone are the same on both sides of the faults and are the same as those in the country rocks. This constancy of dip indicates that the folds in the country rocks replacing the faults in the granite must have steep axes. Folding about steep axes cannot account for the narrowing of the outcrop of the basic rock to the south-east of the faults. This narrowing preserves the smooth outline of the basic envelope and it appears to have been produced at the same time as the faults by movements within the envelope parallel to the edge of the granite. This type of movement involving strike faulting and the vertical displacement of masses of various rocks within the epidiorite and hybrid gneiss zone would account for the present distribution of the various rock types in that zone.

It has not been possible to distinguish mineralogical changes associated with the fault movements and the much greater retrograde changes referred to in the footnote above may have swamped any evidence there might have been. The Shannawon and Bunnagippaun faults are in some respects similar to much smaller scale structures described by Cloos and others and ascribed to the later phases of granitic intrusion. A mappable increase in the number of quartz-

porphyry dykes of the Galway granite radial dyke swarm has been recognized near the Bunnagippaun fault and this suggests that granitic magma was still available during the period of fracturing.

The Eastern and Southern Borders

Most of the eastern border of the granite is hidden beneath the Carboniferous but steeply dipping hybrid gneisses are exposed over a small area in Galway city and on the shores of Lough Atalia immediately to the east. The boundary of the granite runs from north to south through the city. At Salthill, 1½ miles west of Galway, there are exposures of fine-grained granite cutting the porphyritic adamellite and both here and farther north the Geological Survey have mapped numerous porphyries.

On the southern border the country rocks are exposed only on Gorumna and Lettermullen islands. The straight northern shore of Galway Bay between Salthill and Cashla Bay marks the place where a gently inclined surface, probably the sub-Carboniferous erosion surface, rises out of the sea. This straight shore does not appear to be structurally controlled.

The geology of the islands has been recently described by McKie and the writer (McKie and Burke, 1955). The Ordovician (?) pillow lava, greywacke, and conglomerate sequence on them is intruded and hornfelsed by the Galway granite. There is no reaction zone and porphyritic adamellite reaches to the contact or is separated from it by only a narrow selvage of aplogranite. The level of intrusion seems to have been much higher than that exposed on the other borders of the granite and the granite does not appear to have been as close to thermal equilibrium with its country rocks as it was elsewhere.

Conclusion

The Galway granite exhibits features appropriate to various stages of the granite series (Read, 1950). Mixed rocks of the type usually associated with the margins of early, or low level, bodies occupy a wide belt in the north-east while in the same area there are flow structures and fractures of a high level type. This association may well be due to the influence of the containing envelope of basic rocks which by offering resistance to injection and permeation by the granite prevented its being disseminated in the Connemara schists at an early stage and thus contained it until it became sufficiently mobile to rise as a diapir. The accommodation of the late fractures within the basic rock envelope suggests that when the uprise did occur granite and envelope moved together as a smooth body within the Connemara schists. The form of the fractures indicates that the movement of the granite had both an upward and an outward component.

ACKNOWLEDGMENTS

This work on the Galway granite was done at various times between 1951 and 1956, firstly whilst a student at University College, London, and later while on the staff of the University College of the Gold Coast. My thanks are due to the staffs of the Geology Departments of both colleges and especially to Professors Hollingworth and McCallien for their advice and assistance.

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The Insertion of Septa in the Later Growth Stages of *Palaeosmilia murchisoni* (Edwards and Haime)

By G. R. Coope

(PLATE XV)

Abstract

In the later growth stages of *Palaeosmilia*, minor septa are inserted simultaneously on both sides of each newly added major septum and they originate high up near the growing crest of this major septum. Thus, a minor septum occupies the interseptal space in which the next major septum will be inserted. The next major septum develops directly upon the axial edge of this minor septum and it originates deep down in the calyx. The similarity is pointed out between the septal insertion in *Palaeosmilia* and in the more typical aulophyllid (clisiophyllid) corals.

Introduction

THE insertion of septa in the later growth stages of typical aulophyllid (clisiophyllid) corals has been described in a previous paper (Coope, 1956). *Palaeosmilia* (Edwards and Haime) is a well-known genus of Carboniferous coral which has a wide dissepimentarium and long minor septa (Text-fig. 1) and which is included by Hill, 1956, in the Aulophyllidae though it does not possess the more usual aulophylloid axial complex. The object of this investigation is to describe and compare the septal insertion in *Palaeosmilia* with that in the typical Aulophyllidae.

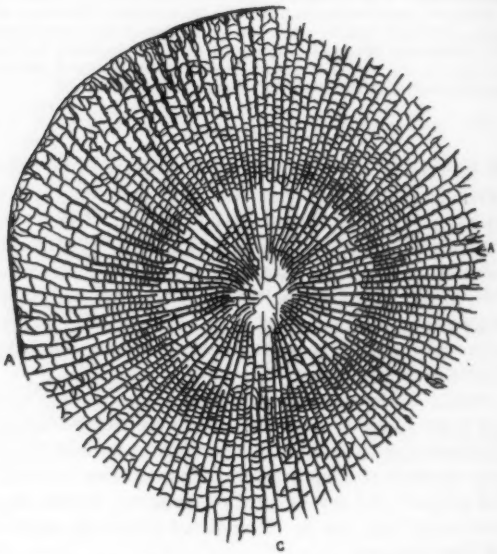
The method of investigation was the same as that which was employed in the study of septal insertion in the Aulophyllidae. Serial parallel surfaces were ground across corals at measured intervals and these were recorded photographically. Thin sections were also made of various stages in the development of the septa. In this way it was possible to study both the development of individual septa and the details of their structure.

Most of the corals investigated were beautifully preserved specimens from the Avon Gorge at Clifton. Others were also studied from Eglwyseg Rocks near Llangollen, Denbighshire, and from various localities in the Carboniferous limestone of England.

Description of Septal Insertion in *Palaeosmilia*

The addition of septa at the alar fossula of an almost mature specimen of *Palaeosmilia murchisoni* is demonstrated in the selected serial sections illustrated in Text-fig. 2. In both the alar and the cardinal fossulae the order of appearance of new septa and their subsequent development is the same, so that the description which follows is equally applicable to the septal insertion in either fossula.

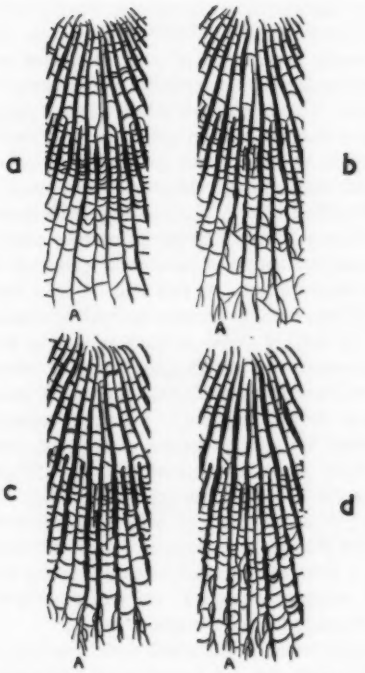
On each side of the most recently formed major septum there appears a small septum, some distance in from the periphery of the coral but within the dissepimentarium as it is seen in transverse section. The actual position of insertion of these septa is by no means constant since they may appear near the periphery of the coral or, more usually, they may appear among the innermost dissepiments (Text-fig. 2*b*). Both septa are usually inserted almost simultaneously, though rarely one of the pair appears some considerable time before its partner—this delay is probably caused by a temporary lack of



TEXT-FIG. 1.—Transverse section of *Palaeosmilia murchisoni* from Clifton. A = alar septum ; C = cardinal septum. Specimen BU702, × 2.

space between the major septa. In transverse section the peripheral ends of the new septa frequently appear to lean upon the young major septum (Pl. XV*b*) and occasionally their axial ends do likewise. In cases where the new septa are not in contact with the young major septum, their ends—both peripheral and axial—usually terminate freely in the spaces between the dissepiments. The incoming of new septa beside the young major septum frequently upsets its growth so that it becomes attenuated, or even discontinuous between the two new septa ; this is most noticeable where the new septa lean upon

the young major septum. The subsequent growth of the two new septa is both peripheral and axial (Text-fig. 2*c*). The peripheral ends ultimately reach the rim of the coral whilst the axial ends grow inwards until they attain the length of the minor septa. At this stage



TEXT-FIG. 2.—A series of surfaces ground across an alar fossula of *Palaeosmilia murchisoni* from Clifton. Intervals between surfaces a–b 1 mm.; b–c 1 mm.; c–d 1·5 mm. Specimen BU702, × 3.

in development, the new septum on the counter side of the young major septum ceases to grow inwards and stays as a minor septum throughout the remaining length of the coral. The new septum on the cardinal side, however, has two alternative methods of subsequent development. Either it remains as a minor septum, if the coral has reached the cylindrical stage, or it may be extended axially to form the next major septum. This axial extension may at first be very attenuated (Text-fig. 2*a*) or it may even be discontinuous, temporarily, with the small septum upon which it developed (Pl. XV*a*). With further

growth, however, these signs of discontinuity disappear. The axial ends of the new major septa frequently lean towards the previously formed major septa. As the new major septum approaches maturity a small septum appears on each side of it and these then develop in the manner described above.

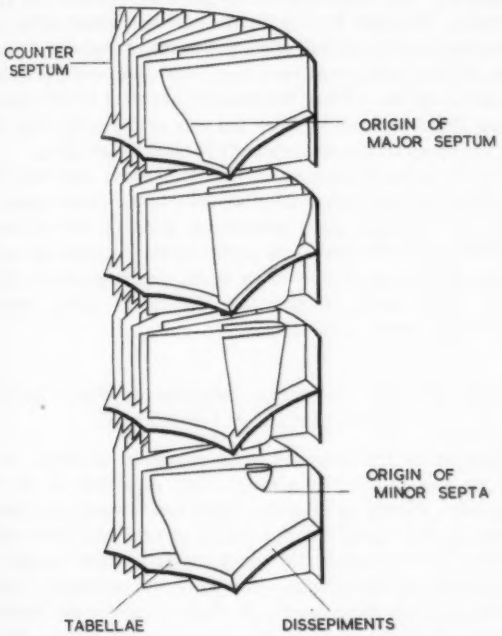
Interpretation

The simultaneous appearance of a small septum on each side of a newly inserted major septum presents a problem of the identity of these small septa. Two alternative interpretations are possible.

The two septa inserted one on each side of a new major septum may be interpreted as minor septa for the following reasons. These two septa, which are inserted almost simultaneously, appear to be homologous structures since in their early growth stages the development of one of them is mirrored by its partner and it is only when they have attained the length of the minor septa that they may differ in their further development. At this stage both of them may remain as minor septa if the coral has become cylindrical when septal insertion ceases ; but if a further major septum is due to be added at the fossula, the septum on the cardinal side may be extended axially to form the next major septum. In further support of this interpretation, the early stages in the development of the major septa were frequently thin and somewhat flexuous extensions of what appeared to be otherwise normal minor septa and occasionally the young major septa developed upon the side of these septa (Pl. XV*a*). These signs of discontinuity, however, disappeared with further growth of the major septa. For these reasons it is suggested that the minor septa were inserted on *both* sides of the most recently formed major septa and that the major septa originated as axial extensions of those minor septa which thus occupied the fossula.

In the alternative interpretation, the septa inserted on each side of the young major septa are not homologous structures ; the one on the counter side is still a young minor septum, but that on the cardinal side may be interpreted as a young major septum from its first appearance. There are three main difficulties to this interpretation. Firstly, the septum inserted on the cardinal side of the young major septum becomes a normal minor septum if the coral has reached the cylindrical stage. Secondly, the discontinuities in the development of this septum, mentioned in the previous paragraph, are difficult to explain if this septum has been a major septum from its first appearance. Thirdly, the two small septa are inserted almost simultaneously and do, in fact, appear to be homologous structures for the reasons given above. It is, therefore, suggested that this alternative should be rejected in favour of the former interpretation.

In the determination, from transverse sections, of the positions of origin in the calyx of the major and minor septa, an understanding of the shape and structure of the calyx is of importance. In *Palaeosmilia* the floor of the calyx is made up of a wide peripheral zone of dissepiments which slope downwards and inwards towards the axis of the coral and a central zone of subhorizontal tabulae, or more typically tabellae, which rise towards the axis where frequently there is a



TEXT-FIG. 3.—Diagram of an alar fossula in *Palaeosmilia*, dissected to show the insertion of the septa. Vertical scale greatly exaggerated.

shallow depression. A single transverse section may, therefore, cut through several successive calicular floors. The rim of the calyx is thus represented by the periphery of the section and the deepest part of the calyx by the boundary between the dissepimentarium and the tabularium. The septa are radial vertical plates which extend up into the calyx through the calicular floor and whose crests slope downwards from the rim of the calyx towards the axis of the coral.

Since the minor septa first appear within the dissepimentarium, as

it is seen in transverse section, their positions of origin must have been some distance above the deepest part of the calyx. Furthermore, the positions of origin of the minor septa may be more accurately determined from a consideration of the effect of the insertion of new minor septa upon the adjacent young major septum. Frequently it was observed that the insertion of the minor septa upset the growth of the young major septum so that it became either somewhat attenuated or even discontinuous temporarily between the two new minor septa. In order for the insertion of the minor septa to cause this disturbance in the growth of the young major septum, the positions of origin of these septa must have been very close to the growing crest of the major septum. Thus, the position of origin of the minor septa was some short distance in from the rim of the calyx and high up near to the crests of the most recently formed major septa.

The major septa originated in the tabularium and were formed directly upon the axial edges of otherwise normal minor septa. Since the crests of the septa slope downwards from the rim of the calyx towards the axis of the coral, the septa achieve their maximum length deep down in the calyx. The major septa, therefore, which developed upon the axial edges of normal adult minor septa, must have originated deep down in the calyx.

Comparison Between the Septal Insertion in *Palaeosmilia* and More Typical Aulophyllidae

In *Palaeosmilia* the mode of septal insertion is similar in many respects to that which has already been described in the typical *Aulophyllidae*. Firstly, in all these corals minor septa are inserted on *both* sides of each newly inserted major septum and their peripheral ends frequently lean upon the young major septum, though this is more noticeable in *Palaeosmilia*. Secondly, the positions of origin of the minor septa, in these corals, are high up above the floor of the calyx and near to the crests of the newly inserted major septa. The insertions of the minor septa differ in that they originate in *Palaeosmilia*, some distance in from the rim of the calyx whilst in the typical *Aulophyllidae* they originate at, or close to, the rim of the calyx. This difference may be due to the relatively much wider dissepimentarium in *Palaeosmilia*.

Since *Palaeosmilia* has long minor septa, it is appropriate to compare the insertions of the major septa with those aulophyllids only which also had long minor septa since in these corals the long minor septa complicated the mode of insertion of the major septa. In *Palaeosmilia* and in these aulophyllids the major septa are inserted directly upon the axial edges of the minor septa which occupied the fossulae. In all

C
(*a*)

A
(*b*)

SEPTAL INSERTION IN *PALAEOSMILIA*.

these corals the major septa originated in the deepest part of the calyx.

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EXPLANATION OF PLATE XV

(*a*) Transverse section in the region of the cardinal fossula of *Palaeosmilia murchisoni* (Edwards and Haime) from Eglwyseg Rocks near Llangollen, showing the development of a young major septum on the side of an otherwise normal adult minor septum on the right of the cardinal septum (C). Specimen BU703, × 13.

(*b*) Transverse section in the region of the alar fossula of *Palaeosmilia murchisoni* (Edwards and Haime) from Eglwyseg Rocks near Llangollen, showing minor septa developing on each side of the young major septum on the right-hand side of the alar septum (A). Dark limestone matrix may be seen between the septa within the tabularium. Specimen BU704, × 13.

Slow Anti-Dunes and Flow Marks

By Archie Lamont

(PLATE XVI)

Abstract

Antidune wavecrests preserved in mud by contemporaneous currents carrying silt are discussed with reference to some recent criticism. In turbidity currents, at slow rates of directional flow, turbulent eddies may be operative in keeping sediment in suspension. Torose structures and flow marks from the Gala-Tarannon of Southern Scotland are compared with structures probably eroded by turbulent currents in the Gronigel Flysch of the Pre-Alps.

J. E. PRENTICE (1956*a*, p. 398) criticizes my figure of antidunes (Lamont, 1941, fig. 9*c*) as "based on a misconception" because "antidunes in modern rivers have long wavelength and low amplitude". In the same paper (fig. 11) I showed more normal antidunes with wavelength up to about six times the wave height, but may I now explain fig. 9*c* which has the wavelength only twice the wave height? I drew fig. 9*c* from an experiment when, under restricted conditions involving much retardation by friction, the distance being travelled by an eddying body of hot liquid was only about 1 foot per minute. The eddies were initiated at a speed of flow of roughly 15 feet per minute. What struck me most was that individual local eddies continued to rotate after directional flow had stopped.

The experiments were conducted in a tea-cup in which tea or cocoa was stirred briskly till a speed of up to 20 feet per minute was obtained near the periphery. A small quantity of fresh milk, with its very finely divided particles, was then added and turbulent patterns could be observed as rate of movement gradually fell.

Prentice says (1956*a*, p. 395) that when velocity falls a turbulent current passes back through stages of laminar flow to flow which produces normal ripplemarks. What he says is not necessarily true. My experiment illustrated directional flow ceasing long before the last isolated eddies. This implies that even at a low speed of directional flow, eddies may help to keep silt in suspension. This may not be sufficiently realized (e.g. Prentice, 1956*b*, p. 46), nor perhaps the mutual effect of particles of different sizes as discussed by E. G. Richardson (1937, 1938), P. H. Kuenen (1951), R. A. Bagnold (1956). Prentice demands a current of 10 inches per second to transport coarse silt.

Turbulence is the chief factor in the pick up of particles by moving water. It is interesting that particles of 0·1 mm. in diameter may often be more easily lifted and carried away than "colloidal" mud. Again, once turbulence is established in a body of water moving in a certain direction, it is very difficult to get rid of it. Thinking of the

vast bodies of water involved, Pettijohn (1950, p. 170, footnote) claims that flow in marine turbidity currents is not turbulent. Because they are relatively unconfined, however, marine turbidity currents can move faster than any stream on land (Longwell and Flint, 1955, p. 236) and turbulence must spread into such a moving body of water from its margins. Incidentally, Longwell and Flint's text-fig. 14–8 shows that antidunal structures can be very complex, so that there is no need with E. K. Walton (1956*a*, p. 270, fig. 7) to use the term "flame" structure.

An interesting point is that in one illustration (Lamont, 1938, p. 15, fig. 4) erosion on the concave side of one antidune has been halted and is being replaced by deposition of false-bedded layers. Examples of this, in a much more extreme condition, have since been found at the roadside in the Dalveen Pass. Here the structures I have called antidunes can hardly be due to differential loading.

TEXT-FIG. 1.—Slow Antidunes from the Dalveen Group (Gala-Tarannon), Dalveen Pass, Dumfriesshire. Following upon slackening in speed of flow, false-bedded silt has been deposited on the concave sides of the Antidune crests where originally erosion took place. × 1.

Walton employs Kuenen's word "load-cast" for most antidunes, where Prentice introduces Shrock's term "flow-cast". To me, Prentice's fig. 4 (1956*a*, p. 398) is quite clearly of slow antidunes due to an Ammanian turbidity current from the N.W. or N.N.W. direction. Walton doesn't give orientations for his figures (1956*a*, 1956*b*), but from field experience I can quote the following examples:—

(1) Ardwell flags (Caradocian), Girvan, with beds "younging" to north-west, in quarry at right-angled bend of road, ½ mile north of Pinmery farmhouse, Assel Valley, show antidunes induced by currents from north or north-east.

(2) Beds between the Dalveen Group (Gala-Tarannon) and the Lowther Grits, Elvanfoot, dipping to north, in a quarry, ⅜ mile west of junction of Clyde Burn with River Clyde, show large well-spaced antidunes due to a current from west-north-west.

In both cases, at no great distance in the stratigraphical succession above the antidunal beds, we come to coarse grits or a stratigraphical gap. This is also true on both counts for Carboniferous P_{1-2} Beds in County Dublin from which my earliest illustrations of antidunes were derived (Lamont, 1938, p. 15, fig. 4; pl. vi, fig. 1). Formations like these, with many antidunal layers, warn us of increasing tectonic

activity and uplifts. This is the meaning of the antidunes described by McCallien and Tokay (1952, pp. 160–2, fig. 5) from sands and shales intercalated in the Upper Cenomanian boulder beds of northern Anatolia.

P. H. Kuenen has never directly discussed my views on antidunes, and I have been chary of criticizing his papers. I venture now to suggest that the structures with wave height and length approximately equal, as shown by Kuenen and Menard (1952, p. 91, fig. 6, I–II), are slow antidunes. They were formed respectively at 500 cm. and 400 cm. from the " origin " where water mixed with sediment was poured down a slope, and may represent structures caused in underlying mud by the passage of a turbidity current which deposited its load so as to preserve these structures.

An interesting problem is presented by the " diapir " shown by Kuenen and Menard (p. 90, fig. 4). As far as I understand them, Kuenen and Migliorini (1950, pl. 3, fig. A, and p. 98) call this kind of thing a " slump " due to emplacement of overburden, but local pressures due to centrifugal force produced by turbulence could also play a part and cause flow in water-saturated sand (*cf.* Lamont, 1938, p. 15, fig. 5). Even where such a bed becomes practically solid, a sudden shock may yet render it mobile (Boswell, 1948).

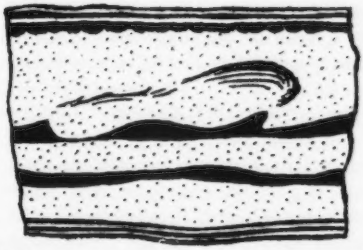
Kuenen and Menard (p. 88) make the point that sudden flows of water charged with sediment produce graded bedding, but constantly fed flows do not. Analogies with what happens in rivers of fairly steady flow must be used with extreme caution in interpreting characteristic greywacke structures like antidunes formed by " bottom currents " which operated (Lamont, 1941) " in open marine waters ". Sorby's figures (1908, pls. xiv–xiv) from the green slates of Langdale, Lake District, show how height of antidunes decreases when there is " more current " and less deposition. One has to think of a quiet marine environment suddenly invaded by a density current carrying mud and silt. The speed of any eddy might, then, be unrelated to forward progression. Indeed, fast and slow eddies, and a few reversed ones, no doubt would become intermingled together. The slow ones and the sediment they carried would, moreover, possess much less centrifugal force to resist external pressure. Slowing down meant collapse, and such bodies of water-laden mud as they settled might even assume thrust structures.

Wildly irregular antidunes in the Borrowdale slates have the wave-length very short in relation to height. They are possibly among the slowest antidunes known geologically. In keeping with this they are buried in fine sediment, and they may have contained H_2S which helped to balloon up some of the structures. The former presence of H_2S is supported by pyrites which has crystallized in the coarser layers,

but one never sees the " bubbling " appearance so characteristic of Forest Marble in which muds generated methane.

Antidunes, on the other hand, with the wavelength more than six times the wave height, like those in the Ordovician Ardwell Group, Girvan, and some of those in the Silurian Dalveen Group, Dumfriesshire, are usually preserved in an incursion of sand or silt. The coarseness of the deposit in which the antidunes are enclosed may thus give some indication of the rate of flow as it was just before the final arrestment.

Those who interpret dynamic antidunes as static load-casts do not take heed of the fact that as often as not antidunes were formed under very thin sedimentary cover. A good example is that in the possibly Llandeilo Carrigaghalia Series on the north side of Doneraile Cove, Tramore, County Waterford (Lamont, 1939*a*, p. 329, fig. 45). The Series includes tuffs, muds, and cherts. The antidunes are in muds succeeded by thin ashy layers. The cherts, so far as I know,



TEXT-FIG. 2.—Antidune Wavecrests in Carbonaceous Claystone (Black) preserved in Acid Tuffaceous Material (dotted) (Benson's Fig. 11 reversed). Tamworth Series (Middle Devonian Geosyncline). Railway-cutting, Nemingha, New South Wales. × ½.

show no antidunes. They may have accumulated in quiet intervals, and suggest that the beds were not of shallow origin.

My first idea about antidunes came to me from reading in the *Illustrated London News*, around 1935, a popular account of some work on aerodynamics by Geoffrey I. Taylor. S. M. K. Henderson's figures (especially 1935, pl. ii, fig. 3) of what he called " ripples " in the Ardwell flagstones had just appeared. The concavity of the crests, with some of the material carried away in a kind of spume, irresistibly bore in upon me that they were antidunes. I went on (Lamont, 1936) to apply this to claystone ripples in tuffaceous material described by W. N. Benson (1915) from the Devonian geosyncline of New South Wales. In one case the illustration seemed to be upside down, but the antidunes were readily identifiable, because one of the crests had

been completely carried away in a graceful open spiral (Lamont, 1939, p. 15, fig. 54). As this figure is not very well known it is reproduced as Text-fig. 2.

Shrock (1948, pp. 112–13, figs. 69, 70), it should be noted, has reproduced two of my other figures.

Examples of probable antidunes described by several writers have been referred to (Lamont, 1939*a*, 1939*b*, 1941). For further examination I now wish to call attention to the " crinkled " bases of grey quartzite laminæ in the Pritchard formation at the bottom of the Belt pre-Cambrian of Idaho (Shenon and McConnell, 1940, pp. 438–440, fig. on p. 439). These have been referred to as exhibiting " pit and mound " structures.

Another pre-Cambrian example occurs in the " varves " of the phyllites belonging to the Tampere schists in south-west Finland. From thence probable antidunes have been figured by A. Simonen (1953, p. 24, fig. 5). They are in graded greywackes associated by Eskola (1932) with cold conditions.

It is not always possible to make a dogmatic separation between antidunes due to turbulence and some small-scale slump and pressure structures. A case in point is that of a disturbance in Pleistocene glacial clays figured by R. G. Carruthers (1939, pl. xxi, fig. 4) and later by Fairbridge (1947, p. 114, fig. 6B). Here there is thickening on the convex side of an overfold with thinning on the other, and breakage of one bed in a manner equally possible in thrusting or slumping. It is just possible, as suggested in other connections by Dunnington (1945, p. 247) and Boswell (1948) that, under sudden shock, the thickened bed became " liquid " with migration of the sand to positions of least pressure. Caution in interpreting such structures must still be a rule, but an experienced geologist can generally distinguish flowage, or other movement of incompetent beds after deposition, from ripplemarks of various kinds formed primarily by movement of water over the ripple-marked layer. When, for instance, Fairbridge (1948, p. 186) reports antidunes in the Trias beds at Shorncliffe, Queensland, and is able to determine that they were probably induced by a sudden current following a slump, there is every likelihood that he is correct and not dealing with a product of static differential weighting, or with pressure effects on preformed ordinary asymmetrical ripples.

In a paper on the Gronigel Flysch (Paleocene–Eocene), which is regarded as laid down in a " fairly deep " trough with a land mass not far to the north-west, J. C. Crowell (1955) has described a number of structures which bear considerable resemblance to those in the Scottish Gala-Tarannon greywackes and sub-greywackes, which seem to have been deposited in a sea separating the Highlands from the

Lake District. Crowell holds that some of his flute-casts were eroded by turbidity currents, i.e. turbulent currents laden with sand, etc. His " torose load-casts " are parallelled in the " bulbosities " at Pirn Craig Quarry, near Innerleithen, Peeblesshire (Walton, 1955, pl. i*a*), and on the roadside, 2½ miles south of Traquair (Pringle and Eckford, 1945, pl. ii). Other instances are to be seen in the Curlingstone Quarry, Abington, Lanarkshire, which are probably Gala-Tarannon, and in Tieveshilly Old Quarry, County Down, Northern Ireland, where greywacke grits succeed dark *Rastrites* shales. In each case the " bulbosities " are fillings of basins up to a foot across and sometimes longer, with a steep or overhanging side and a gently sloping side. The elongation indicates flow direction and the current probably came from the steepened side which may have been undercut by turbulent flow.

In Plate XVI, fig. 2, an example of flute-casts, some only incipient, is figured from the Pentland Hills. Plate XVI, fig. 1, shows " bulbosities ", on the base of a sandy bed from the same area. For Plate XVI, fig. 1, flow, which excavated the original depressions, was probably from the bottom of the page towards the top. That the structures are essentially of shallow-water origin is shown by the worm track, interrupted where small pools of water remained.

At Thorn Bush Quarry, Selkirk, possible flute-cast runnels on a very small scale can be seen merging with ripple marks, though they lie at right-angles to the ripple direction. An ebbing tide might explain this (J. M. Clarke, 1918). Tidal and other forms of turbulence (*cf.* Taylor, 1920) must be kept in mind until a final explanation is reached.

As a speculation, I hazard that in the Middle and Upper Pliocene of the Ventura Basin of California, pockets filled with coarse graded sandstone (Natland and Kuenen, 1951, p. 96, fig. 16) were excavated by turbulent water which also carried the sand. This is the only way I can explain the overhanging margins of some of the little basins. On this argument, Natland and Kuenen's " asymmetrical, cuspate ripple marks " seem to be antidunal in origin. Their constancy of direction over wide areas makes it impossible to treat them as static load-casts and Kuenen does not attempt it (p. 105).

Kuenen in another paper (1952, p. 32) distinguishes between (1) " flow cast " attributed to differential loading (cf. Kuenen, 1953, p. 22, fig. 10), but more likely to be due to turbulent scour succeeded by paene-instantaneous deposition of the upper bed, (2) slump structure with sliding of the base of the slumped beds and truncation of their top by erosion, and (3) a " convolute bed " which is due to a directed current inducing wave crests which overhang away from the direction of flow. As the crests in (3) are narrower than the troughs, it is quite possible that the sandy sediment was being carried

by turbulent water and that each trough was formed around the axis of an eddy. Kuenen (p. 33, fig. 4) shows an example from the Aberystwyth grits, which is closely similar to that in J. L. Rich's photographs (1950, p. 729, fig. 9; p. 730, fig. 10).

In conclusion, I should say any hypothesis is inadequate which does not take account of turbulent scouring and centrifugal force exerted by eddies during the emplacement of greywacke layers. The ubiquitous overhanging structures in the tops of mud and fine-grained strata can rarely be due, even at second hand, to ordinary vertical pressures. Where tongues of mud curve in opposite directions it is much better to invoke reversed eddies. I have occasionally observed ordinary sedimentary ripple-marks passing into " sharpened " structures which could be mistaken for antidunes. This, however, is usually due to tectonic pressure after consolidation.

The term " flame " structure introduced by Walton (1956*a*) is not luminous, although it may recall some work on the alleged effect of pressure on flames by Dr. Marat who met a sudden death in the French Revolution.

I have followed the Editors' suggestion in showing this paper to Drs. Kelling and Walton, and I have had the opportunity of seeing the manuscript of their paper published currently in this journal.

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JESS COTTAGE,
CARLOPS,
PENICUIK.

EXPLANATION OF PLATE XVI

FIG. 1.—Base of silt bed with cast of flow-marks merging into "Bulbosities". Cast of burrow and tracks of *Planolites* sp. (top middle and left). Red Bed in Upper Gala-Tarannon, small quarry at south-east end of North Esk reservoir, Pentland Hills. × 1.

FIG. 2.—Base of thin silt bed with cast of groove and flute-marks. Green Cleuch Siltstones (Upper Gala-Tarannon), gully west of Green Cleuch, Pentland Hills. × 1.

FIG. 1.

FIG. 2.

FLOW MARKS FROM GALA-TARANNON BEDS.

Load-cast Structures : Their Relationship to Upper-Surface Structures and their Mode of Formation

By G. KELLING AND E. K. WALTON

(PLATE XVII)

ABSTRACT

The form and distribution of load-casts suggests a genetic connection with structures previously formed on the upper surface of the underlying bed. On analogy with salt-dome development, the growth of load-casts and associated flame-structures is attributed to the density contrast between upper and lower bands and differential loading caused by the projections and depressions formed by the upper-surface features. This hypothesis is the basis of a new classification of load-cast structures.

INTRODUCTION

STRUCTURES occurring on the under-surfaces of many greywackes and sandstones have received considerable attention in recent years and some confusion has arisen concerning their classification (see Prentice, 1956, and Kuenen and Prentice, 1957).

Of frequent occurrence among these structures are those known as load-casts (Kuenen, 1953, Flow casts, Shrock, 1948, p. 156), and these consist of sandy, coarse-grained material forming bulbous pockets which project downwards into the underlying shale. Following Shrock, the formation of load-casts has been generally ascribed to unequal loading of a soft mud by coarser-grained, overlying material. Kuenen (1957) has treated some aspects of this process and in the present paper an attempt is made to carry the analysis a step further.

In addition, curved, pointed tongues of shale, as seen in vertical sections, penetrating into overlying beds of greywacke, have been described as " antidunes " (Lamont, 1938), and " flame-structures " (Walton, 1956*a*). Lamont was influenced by the work of Taylor (1935 and 1936), impressed by the regular spacing of the structures and their resemblance to antidunes (Gilbert, 1914), but Prentice (1956) and Walton (1956*a*) doubted this mode of formation. Kuenen and Menard (1952) produced flame-structures experimentally and ascribed their formation to " (1) drag exerted by the turbidity current on the watery clay film of its bed, (2) local settling and squeezing caused by the rapid accumulation of overburden on the highly mobile foundation ".

During investigations of the Lower Palaezoic rocks in the Southern Uplands of Scotland, the authors have been impressed by the fact that load-cast structures constantly exhibit forms which can be correlated with those of upper-surface structures, and by the coincidence of flame-structures and load-casts. This correlation has been

alluded to previously only for individual occurrences. Fuchs (1895) commented on the resemblance of certain mudflow structures, on the lower surfaces of Flysch sandstones, to ripple-marking, but he maintained that there was no genetic connection, and Bucher (1919) suggested that they might be called pseudo-ripples. Lately, Crowell (1955) has noted that " there may be transitions between load-casts and flute-casts " while Kuenen (1957) accounts for some load-casts by the deformation of pre-existing drag-marks and flute-casts. We wish to emphasize that the correlation between previously formed upper-surface structures, load-casts, and flame-structures is a general one. Furthermore, recognition of this leads directly to an explanation of the origin of load-cast structures and clarifies the problem of nomenclature and classification.

TABLE 1

UPPER-SURFACE STRUCTURES	UNDER-SURFACE STRUCTURES	
	UNDEFORMED	DEFORMED (Flow-casts, Shrock, 1948 Load-casts, Kuenen, 1953)
Group I.		
A. *Grooves* (Drag-marks, Kuenen and Sander, 1956)	*Groove-casts* (Shrock, 1948)	*Groove-load-casts* (in part, torose load-casts, Crowell, 1955) (in part, Korkzieher Zapfen, Rücklin, 1938)
B. *Flutes* (Flow-markings, Rich,	*Flute-casts* (in part the flute-casts of Crowell, 1955) (Flachzapfen and in part Einfache Zapfen-wulste, Rücklin, 1938)	*Flute-load-casts* (Load-casts and in part flute-casts and torose load-casts, Crowell, 1955) (Flow-rolls, Rich, 1950) (Lobate rill-marks, Clarke, 1918) (Einfache Zapfen-wulste in part and Korkzeiher-Zapfen in part, Rücklin, 1938)
Group II.		
A. *Transverse Ripple-marks*	*T-Ripple-casts*	*T-Ripple-load-casts* (? Flow-casts, Prentice, 1956)
B. *Longitudinal Ripple-marks*	*L-Ripple-casts*	*L-Ripple-load-casts*
C. *Interference Ripple-marks*	*I-Ripple-casts*	*I-Ripple-load-cast*

CLASSIFICATION

Table 1 summarizes our conclusions and includes the synonyms which, in the light of the relationships discussed below, in our view now become unnecessary. The table does not attempt to cover all the structures described from under surfaces, but only those where load-casts and flame-structures are known to be involved.

In the ensuing discussion it should be noted that the upper surface features referred to now occur *below* the under-surface structures. In order to avoid possible confusion we have used upper-surface consistently throughout in relation to the underlying fine-grained bed, and under-surface features relate to the overlying coarser-grained bed.

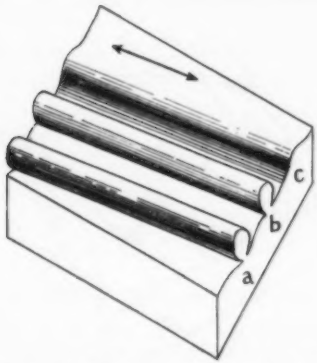
THE FORM OF LOAD-CASTS

Group I.

Load-casts often of large size, elongate; either linear and con-

tinuous, *or* lobate, discontinuous; usually irregularly spaced; associated flame-structures well-developed.

A. *Groove-load-casts.*—These load-casts are characteristically long and often remarkably straight. They vary in size up to about 1 ft. across and about 9 in. deep. Their similarity to groove-casts is clear and convincing. Text-fig. 1 is a composite diagram illustrating their form as it is often seen in inverted sequences in the Southern Uplands. In this diagram, (*a*) represents an extreme form of groove-load-cast, with marked indentations and long, slender flame-structures; (*b*) is an intermediate, and more common form, showing less pronounced indentation and short, stubby flame-structures; while (*c*) represents



TEXT-FIG. 1.—Groove-casts (*c*) and groove-load-casts (*a*) and (*b*). The structures are parallel with the current which, as the arrow indicates, may be from left or right. Bed inverted.

an undeformed groove-cast. Examples have been described from the Silurian rocks of Peeblesshire (Walton, 1955, pl. iA). They are also common in the Ordovician rocks of the Rhinns of Galloway and the Wenlock rocks on the west side of Kirkcudbright Bay.

B. *Flute-load-casts.*—One of the best examples of this type has been illustrated by Pringle and Eckford (1945, pl. ii). The structures have the typical tear-drop shape, with one end deep and bulbous and they become wider and more shallow at the other, the down-stream end. Flute-load-casts show considerable variation in size and shape, with the largest reaching up to 10–12 in. long, 8–10 in. wide, and up to 2-3 in. deep at the " nose ".

Similar structures have been described simply as load-casts by Crowell (1955). The form and distribution of these deformation-structures is such as to leave little doubt of their close relationship

with those similar structures which show no deformation, such as the flow-markings of Rich (1950) and Kuenen (1953*a*) and the flute-casts of Crowell (1955) and Prentice (1956). Indeed, Kuenen (1953*b*, pl. B2) illustrates one surface from the Rhinns of Galloway which shows both undeformed flute-casts and deformed flute-load-casts.

Text-fig. 2 is a diagrammatic representation of these structures showing various degrees of deformation and illustrating in plan and section the forms which may be developed. Undeformed flute-casts are represented at (*a*) and (*b*), all the other structures illustrated being deformed to some extent. The deformation is indicated by the indented form and the occurrence of large flame-structures, which can be seen in both longitudinal and transverse views.

TEXT-FIG. 2.—Flute-casts (*a*) and (*b*) and flute-load-casts. Structures inverted, current from bottom left.

The torose load-casts of Crowell (1955) are of two types. One is similar in shape to the structures above and may be simply a flute-load-cast with the deeper end down-stream. The other type is longer and may have a composite or spiral form. Now, Kuenen (1953) noted groove-casts of similar form so that this second type is one of our Group IA—the groove-load-casts. Rücklin (1938) described short, spiral forms (Korkzieher Zapfen) which we regard as flute-load-casts.

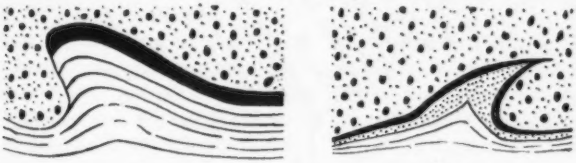
The large flame-structures associated with the flute- and groove-load-casts often provide evidence of the action of both erosion (of the underlying laminae) and of later deformation (of both coarse and fine-grained beds). Text-fig. 3 shows a clear example from the Ordovician rocks of Morroch Bay in the Rhinns of Galloway. The structures illustrated by Walton (1956*b*, fig. 8) show distinctly the squeezing upwards of the fine-grained bands.

Group II.

Load-casts with a regular pattern in plan; deformation often slight, and flame-structures small.

A. *Transverse Ripple-load-casts* (Pl. XVII, fig. 1).—Asymmetrical ripple-marks are a common feature on the siltstones at the top of greywacke beds, but few examples of the corresponding load-casts have been described (see below). One example, where strong indentation is developed, is exposed at Jameson Point, in the Ordovician rocks of the Rhinns of Galloway (Pl. XVII, fig. 1). These structures have a wavelength of 2–3 in., comparable with that of the normal transverse ripple-marks; they anastomose in a similar manner, and the current-direction as determined from associated cross-lamination, is normal to the length of the load-casts.

Prentice (1956) describes as " flow-casts " structures which are developed at right-angles to the prevailing current. This also suggests

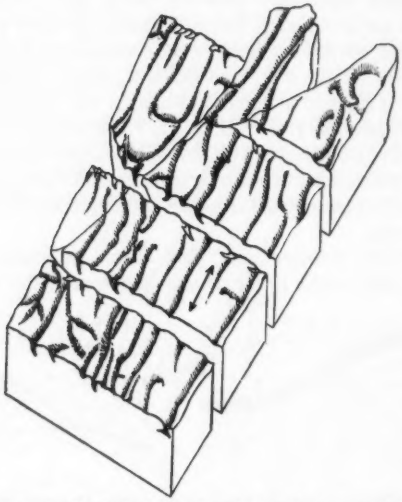


TEXT-FIG. 3.—Flame-structures, Ordovician rocks, Morroch Bay, Rhinns of Galloway.
(*a*) Erosion has preceded deformation, slight thickening later.
(*b*) Pronounced thickening of the laminae during the growth of the structure.
The height of the structures is 2·5 cm.

deformation from a surface with transverse ripple-marks. It is our opinion that the use of the term " flow-cast " is undesirable where the structures show a connection with upper surface features. Flowage, as well as downwards-sagging, may have played a small part in the formation of any of the structures described here. Where there has been a great deal of movement resulting in the complete loss of any initial pattern, then " flow-cast " may be applicable, but otherwise the use of a separate term obscures the genetic relationship between the load-cast and the original structure.

B. *Longitudinal Ripple-load-casts* (Pl. XVII, fig. 2).—Structures on many greywackes, siltstones, and mudstones in the Rhinns of Galloway appear to be longitudinal ripple-marks. Details supporting this conclusion are to be given elsewhere (Kelling, in preparation). Of direct interest to the present study is the fact that in many cases flame-structures are developed and it is evident that slight load-casting has taken place.

Text-fig. 4 is based on a specimen from the Hawick rocks, near Binks, Roxburghshire. It shows the under surface with casts of longitudinal ripple-marks while a series of sections reveals flame-



TEXT-FIG. 4.—Longitudinal ripple-load-casts based on a specimen from Binks, near Hawick.

Lower surface shows ripple pattern. Sections show flame-structures, asymmetrical, pointing either to the right or left, and symmetrical. At the top left is a symmetrical flame structure, one limb of which has been turned back on itself. Structures parallel with the current.

Specimen is 30 cm. long. The flame structures have been exaggerated slightly; they average 3 mm. in length.

structures developed in the crests. It will be noted that symmetrical and asymmetrical flame-structures occur and the latter may be directed in different directions even along the same crest.

C. *Interference Ripple-load-casts.*—An example of this type is illustrated in Pl. XVII, fig. 3, which is also taken from the Hawick rocks, near Binks. The pattern suggests original interference ripple-marks and the section view shows small flame-structures. It is possible that the "flow-cast" illustrated by Shrock (1948, fig. 117) was also developed by deformation of original interference ripple-marking.

THE FORMATION OF LOAD-CASTS

As indicated earlier, the formation of load-casts has been ascribed to unequal loading. The observed form of these structures and their

relationship to upper-surface features leads inevitably to the conclusion that their formation is the result of loading rendered unequal by the presence of original irregularities on the upper-surfaces of underlying fine-grained beds.

In this we may profitably draw an analogy with the development of salt-domes, and particularly germane to this discussion is a series of experiments carried out by Parker and McDowell (1955) who used scale models to investigate the initiation and growth of salt-domes.

Their results show that when a heavier layer immediately overlies a lighter layer then any original upward projection of the lower stratum into the upper tends to produce a state of unstable equilibrium. The weight of the relatively heavy upper layer is less over the upward projections from the lower layer than it is over the intervening parts of the lower stratum. If this difference is sufficiently great then the downward pressure of the upper layer causes the underlying lighter stratum to flow towards the projections which, in consequence, grow upwards in diapir fashion.

Now, in the case of load-casting we have similar conditions in that the lower muddy layer, mainly due to its higher water content, has a lower density than the overlying sandy layer. Figures given recently by Hamilton and Menard (1956) show the probable density contrasts (e.g. coarse sand — 2·08, sand-silt-clay — 1·44), but variations would occur due to differences in the grain-size, composition, and, in the case of the underlying layer, in the amount of compaction. Moreover, if the surface of the muddy layer was characterized by ripple-marks, grooves, or flutes these would provide original irregularities, of the nature of projections and depressions, on the upper surface of this layer. By analogy with Parker and McDowell's experiments it can be inferred that, after the accumulation of a sufficient thickness of the overlying sediment, there would be flowage of the muddy sediment towards relatively elevated crests and concomitant movement of the sandy material into the depressions.

In this way flame-structures would inevitably be developed from the upward-flowing mud, and load-casts would grow by sinking and slight lateral movement of the coarse-grained overburden in the original depressions. One puzzling feature of flame-structures is their pointed nature in contrast to the rounded tops of salt-domes. Load-casts associated with grooves and flutes often attained a considerable size because of the initially large dimensions of these depressions, whereas those associated with ripple-marks generally exhibit a smaller amount of growth, related to the lesser dimensions of the ripple-ridges. Transverse and interference ripple-load-casts are, apparently, rather rare and this may be due to the slightly different densities of the sediments in which they were formed.

Parker and McDowell found that growth of the domes was stopped most effectively by increasing the thickness of the overburden and this may well have been the determining factor in the cessation of growth in the load-cast structures.

Experiments with sand and mud layers have been begun in the Grant Institute of Geology in an effort to establish the relative importance of the various factors involved in the growth of flame- and load-cast structure.

Directions of the Flame-structures

Reference has been made to the tendency for flame-structure to be pointed obliquely upwards constantly in one direction. This suggested to Lamont (1938) an origin as antidunes, while Kuenen and Menard (1952) and Kuenen and Prentice (1957) suggested that the drag involved during deposition from a turbidity current would tend to pull over the shale projections.

The examples described above invalidate the antidune hypothesis. It has been shown that when the structures seen in section are examined in plan, they show only rarely the regular crests transverse to the current, and, moreover, regular spacing if present is readily explicable on the basis of their derivation from ripple-crests. These criticisms apply to the interpretation of flame structures as the antidunes of Gilbert (1914). Dr. Lamont kindly showed us the manuscript of his current paper in this journal and it appears that he uses the term " antidune " in a different sense. Some flame-structures have been formed in the way he suggests, by concomitant scouring and filling (see Walton, 1956*a*, fig. 7). Recently Dr. D. A. Bassett and one of us, have found such examples of scour and fill in the Cambrian Hell's Mouth grits in North Wales. However, the majority are connected with " load-casting ".

It would appear, also, that though current-drag may be a contributory factor, it is not the only one. This is particularly the case where flame-structures are developed from longitudinal ripples (Text-fig. 4). Here the current is parallel to the flame-crests. Further, the flame-structures do not always fall in the same direction and, finally, symmetrical, as well as asymmetrical structures occur (Walton, 1956*a*, fig. 4).

It seems probable that the main factor producing the inclination of flame-structures is the subsequent compaction of the coarse-grained bed. Adjustments during such compaction would probably not be exactly vertical, and, in addition, any slight initial slope would tend to favour a more or less regular asymmetry in the flame-structure.

Acknowledgments

We wish to express our gratitude to Dr. D. L. Reynolds for drawing

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EXPLANATION OF PLATE XVII

FIG. 1.—Transverse ripple-load-casts on the base of an Ordovician greywacke bed, Jameson Point, near Kirkcolm, Rhinns of Galloway. Length of scale, 6 inches.

FIG. 2.—Longitudinal ripple-load-casts, on the base of a thin bed of greywacke; Ordovician, old quarry near Cairndonald, Rhinns of Galloway. Coin (diameter 1¼ inches) gives scale.

FIG. 3.—Interference ripple-load-casts, at the base of fine-grained Silurian greywacke. Specimen from Binks, near Hawick.

FIG. 1.

FIG. 2.

FIG. 3.

RIPPLE-LOAD-CASTS

Growth of the glabella of *Dalmanitina olini*

By J. T. Temple

Abstract

Growth of the glabella of the trilobite *Dalmanitina olini* is studied by plotting various dimensions y against the length of the glabellar stalk x which is taken to represent absolute size. The relations are fitted best by linear equations $y = a(x + b/a)$, and for several dimensions the value of b/a appears to be constant. The concepts of absolute and specific growth-rates are discussed in relation to the glabella of *D. olini*.

THE present note supplements some preliminary observations on the growth of the glabella of the Upper Ordovician trilobite *Dalmanitina olini* Temple (1952, pp. 257–8). Data on the horizons and localities of the specimens will be found in the earlier article. The results below are based on material in the Palaeontological Institution, Lund, from the two Scanian localities, Röstånga and Tommarp; material from Conway and Ash Gill Beck is too imperfect for accurate biometrical work.

The following measurements were made :—

(i) length of the glabellar stalk (*st. l.*)
(ii) width (tr.) of the glabella across the occipital ring (*occ. w.*)
(iii) sagittal length of the frontal lobe (*f.l. sag.*)
(iv) ex-sagittal length of the frontal lobe (*f.l. exs.*)
(v) width (tr.) of the frontal lobe at the anterior pits (*ant. p.w.*)
(vi) maximum width (tr.) of the frontal lobe (*f.l. max. w.*).

Definitions of some of these measurements will be found in a recent article (1956, pp. 420–1), together with reasons for considering the length of the glabellar stalk (rather than the total length of the glabella) as the best index of absolute size.

The measurements were made under a microscope with eye-piece micrometer, as projections on to the horizontal plane defined by the outline of the glabellar stalk. This entails some error in the measurement of the sagittal length of the frontal lobe, for during part of early development the frontal lobe plunges steeply down in front towards the pre-glabellar furrow, whereas at later stages this forward slope is much reduced and the whole of the lobe comes to lie more or less in the horizontal plane of the stalk. The projections of the sagittal length at different stages are not strictly comparable, and over much of early development the values so obtained are too small. Growth data for the sagittal length are therefore less reliable than those for the other measurements.

In all, thirty-three specimens (including six protaspides) were measured, but of these only five were more than 2·0 mm. in stalk

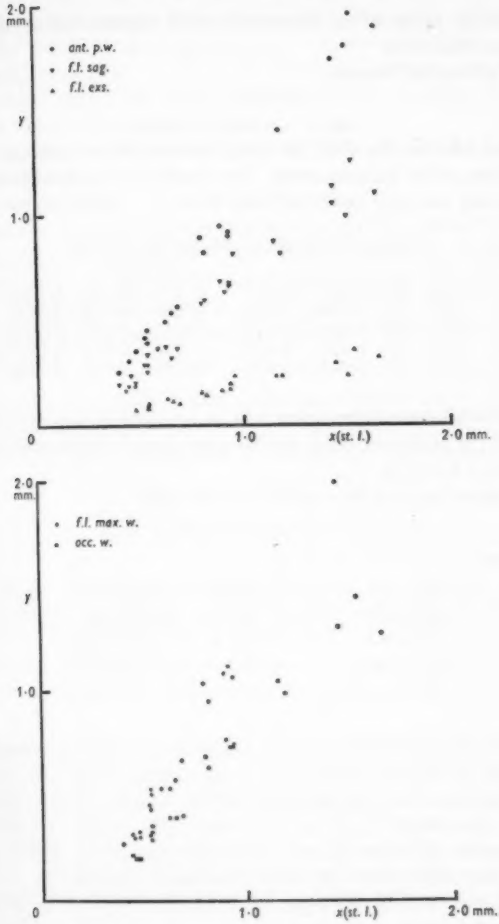
length, so that the results obtained are based primarily on the early period of growth. Furthermore, measurements (iv) and (v) depend on the positions of the anterior pits, and cannot be estimated accurately in the larger specimens in which the pits have disappeared. Many specimens were incomplete in respect to some or other of the measurements.

TABLE I.—MEASUREMENTS OF THE SPECIMENS IN MILLIMETRES
(Figures in italics refer to protaspides.)

st. l.	*occ. w.*	*f.l. sag.*	*f.l. exs.*	*ant. p.w.*	*f.l. max. w.*
0·40	—	*0·19*	—	*0·25*	*0·27*
0·43	—	*0·16*	—	—	—
0·45	*0·22*	*0·18*	—	*0·30*	*0·32*
0·46	*0·21*	*0·23*	—	—	*0·30*
0·48	*0·21*	*0·18*	*0·07*	*0·35*	*0·31*
0·48	—	*0·20*	—	—	*0·33*
0·53	0·32	0·28	0·09	0·41	0·46
0·54	0·30	0·25	0·08	0·39	0·44
0·54	0·33	0·28	0·10	0·45	0·51
0·54	0·36	0·33	0·09	—	0·53
0·59	—	0·36	—	—	0·54
0·63	0·40	0·37	0·12	0·49	0·54
0·66	0·40	0·31	0·11	0·53	0·58
0·69	0·41	0·36	0·10	0·56	0·67
0·80	0·69	0·58	0·15	0·89	1·04
0·82	0·64	0·59	0·14	0·82	0·95
0·90	0·77	0·68	0·16	0·94	1·09
0·92	0·74	0·63	—	—	1·12
0·94	0·75	0·66	0·19	0·90	1·07
0·94	0·74	0·67	0·17	0·91	1·07
0·96	—	0·81	0·23	—	—
1·16	1·05	0·87	0·23	—	1·69
1·19	0·99	0·81	0·23	1·40	1·57
1·45	1·31	1·05	0·29	1·74	2·00
1·45	—	1·13	—	—	2·00
1·51	—	0·99	0·23	1·80	2·04
1·54	1·45	1·25	0·35	1·95	2·15
1·66	1·28	1·10	0·32	1·89	2·15
2·30	—	2·00	—	—	3·43
2·85	—	2·97	—	—	—
3·43	3·19	3·43	—	—	—
3·56	—	3·68	—	—	—
7·53	8·09	6·81	—	—	—

The length of the stalk being taken to represent the size of the glabella, the other variables have been plotted against it, as shown in Text-figs. 1 and 2. The relations all appear approximately linear, and equations have been fitted to the lines by the reduced major axis method of Kermack and Haldane (1950), which is considered more suitable for this purpose than the standard regression techniques used recently in a similar case by Shaw (1956). The equations are of the form

$$y = ax + b,$$



TEXT-FIGS. 1 (top) and 2.—The variables plotted against stalk length (*st. l.*) up to 2·0 mm.

where a and b are parameters, y represents in turn the variables (ii) to (vi), and x is in each case the stalk length.

The parameters a and b, the relevant correlation coefficient r, and the size of the population n for each pair of variables are set out in Table II. It will be noted that the correlation coefficients are high,

and that the values of the intercept b are all negative and significantly[1] different from zero.

The allometric formula

$$y = \beta x^{\alpha},$$

or

$$\log y = \alpha \log x + \log \beta,$$

was also tried on the data, by fitting reduced major axis lines to the logarithms of the measurements. The correlation coefficients obtained in this way are also given in Table II as r'. Except in the case of

TABLE II.—REDUCED MAJOR AXIS DATA

y	x	n	a	b (mm.)	r	r'
occ. w.	*st. l.*	23	$1{\cdot}097 \pm 0{\cdot}013$	$-0{\cdot}294 \pm 0{\cdot}025$	0·9984	0·9862
f.l. sag.	*st. l.*	33	$0{\cdot}989 \pm 0{\cdot}020$	$-0{\cdot}256 \pm 0{\cdot}038$	0·9935	0·9875
f.l. exs.	*st. l*	20	$0{\cdot}221 \pm 0{\cdot}014$	$-0{\cdot}032 \pm 0{\cdot}014$	0·9587	0·9705
ant. p.w.	*st. l.*	19	$1{\cdot}432 \pm 0{\cdot}035$	$-0{\cdot}364 \pm 0{\cdot}034$	0·9943	0·9939
f.l. max. w.	*st. l.*	27	$1{\cdot}673 \pm 0{\cdot}028$	$-0{\cdot}442 \pm 0{\cdot}030$	0·9960	0·9888

f.l. exs. (where the difference is not in fact significant) they are less than for the arithmetic data, and we may consider the linear relations as giving a better fit.

The equations may be rewritten in the form

$$y = a\,(x + b/a)$$

as follows :—

(*occ. w.*) $y = 1{\cdot}097\ (x - 0{\cdot}268$ mm.),
(*f.l. sag.*) $y = 0{\cdot}989\ (x - 0{\cdot}259$ mm.),[2]
(*f.l. exs.*) $y = 0{\cdot}221\ (x - 0{\cdot}144$ mm.),
(*ant. p.w.*) $y = 1{\cdot}432\ (x - 0{\cdot}254$ mm.),
(*f.l. max. w.*) $y = 1{\cdot}673\ (x - 0{\cdot}264$ mm.).

It is then seen that there is a remarkable family likeness between the equations in that the values of b/a are closely similar—in fact, for four of the equations they are equal within the limits of their standard errors. The value for *f.l. exs.* is considerably lower, and although the apparent difference is not quite significant, it is possible that *f.l. exs.* may differ from the other variables in this respect. A mean value of b/a may be obtained by weighting the various estimates

[1] The 5 per cent level of significance is used throughout.

[2] If the calculation is confined to specimens below 2·0 mm. in stalk length, the equation for *f.l. sag.* becomes $y = 0{\cdot}871(x - 0{\cdot}209$ mm.) and in this form was used in 1952 (p. 258) to estimate the hypothetical vanishing point of the frontal lobe. The discrepancy between the two equations, which is probably due to the effect discussed earlier, illustrates the unreliability of *f.l. sag.* data. It leads to a suspicion that the very close conformity of the whole-range *f.l. sag.* value of b/a with the values for the other variables may be partly fortuitous, although there is no question of a *significant* difference in b/a.

with the reciprocals of their variances[1]: this gives a mean of $-0{\cdot}2617 \pm 0{\cdot}0094$ mm. excluding *f.l. exs.*, or $-0{\cdot}2584 \pm 0{\cdot}0093$ mm. including *f.l. exs.* We may, therefore, without making any assumptions about the latter variable, accept a value of about $-0{\cdot}26$ mm. for the common b/a.

The equations (with the possible exception of that for *f.l. exs.*) then reduce to

$$y = a(x - 0{\cdot}26 \text{ mm.}),$$

and, since b/a is the intercept on the x axis, the values of y have a common vanishing point at a stalk length of 0·26 mm. (Text-fig. 3). The significance of this condition is obscure, although it would appear to set a hypothetical lower size-limit to the protaspis of *D. olini* (the smallest known specimen—from Conway—has a stalk length of 0·39 mm.).

In order to show that the close resemblance between the values of b/a from the various equations is not an artefact imposed on the data by the reduced major axis method, the equations for the conventional regression lines have also been calculated and are set out below for comparison :—

(*occ. w.*) $y = 1{\cdot}096\,(x - 0{\cdot}266$ mm.),
(*f.l. sag.*) $y = 0{\cdot}982\,(x - 0{\cdot}252$ mm.),
(*f.l. exs.*) $y = 0{\cdot}212\,(x - 0{\cdot}111$ mm.),
(*ant. p.w.*) $y = 1{\cdot}424\,(x - 0{\cdot}250$ mm.),
(*f.l. max. w.*) $y = 1{\cdot}666\,(x - 0{\cdot}262$ mm.).

It will be seen that although the values of b/a are all slightly reduced—and *f.l. exs.* more than the others so that its difference from them is enhanced—the close grouping of the four higher estimates is not affected.

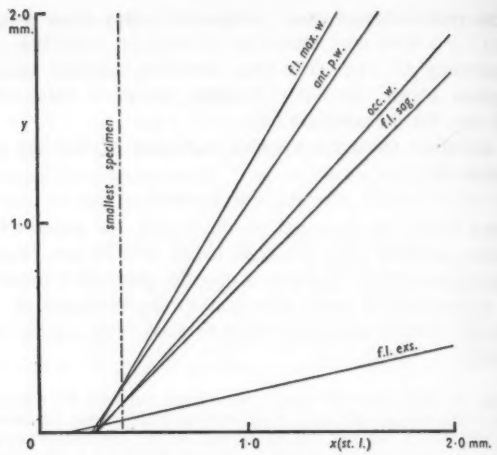
From the relation $y = a(x + b/a)$,

$$\frac{dy}{dx} = \frac{dy/dt}{dx/dt} = a\,;$$

so that for each pair of variables y and x the parameter a represents the ratio of the *absolute* growth-rates (dy/dt and dx/dt) of the variables, and this ratio is a constant independent of the size so long as the linear relation between y and x holds. The absolute rate of growth in sagittal length of the frontal lobe of *D. olini* is thus about equal to that of the glabellar stalk, or about four times that of each of the other glabellar lobes (if we take the rates of the latter to be a quarter that of the stalk), while the rate of growth of the frontal lobe in ex-sagittal length is slightly less (though not significantly so) than that of each of the other lobes.

The *specific* growth-rates ($1/y.dy/dt$ and $1/x.dx/dt$) are usually considered biologically more significant than the absolute rates. For

[1] The variance of b/a is obtained most easily from the inverse form of the reduced major axis equation, $x = a'y + b'$, for b', is numerically equal to b/a and its variance is given by the standard formula.



TEXT-FIG. 3.—The reduced major axes.

the linear equation, the ratio of the specific rates of each pair of variables is :—

$$\frac{dy/ydt}{dx/xdt} = \frac{ax}{y} = \frac{x}{x + b/a}$$

and this ratio (unlike that of the absolute rates) is not independent of size, although it tends to a limiting value of unity as x becomes large in comparison with b/a.

TABLE III.—RATIOS OF THE SPECIFIC GROWTH-RATES OF y AND x AT VARIOUS VALUES OF x, BASED ON THE RELATION $y = a(x - 0{\cdot}26$ MM.)

x (mm.)	$\frac{dy/ydt}{dx/xdt}$
0·4	2·86
0·5	2·08
0·6	1·76
0·7	1·59
0·8	1·48
0·9	1·41
1·0	1·35
2·0	1·15
3·0	1·09
4·0	1·07
5·0	1·05

In the special case of the family of lines $y = a(x - 0{\cdot}26$ mm.), the ratio of the specific rates becomes $x/(x - 0{\cdot}26$ mm.) and is independent of a. For the four variables for which this relation holds, the ratios of the specific growth-rates of all four variables relative to that

of the glabellar stalk are equal at any given value of x, and the ratios decline rapidly and tend to unity in a similar manner as x increases (Table III). The specific growth-rate of *f.l. exs.* (if the latter really differs from the other variables in its growth relations) also declines as x increases, but less rapidly than the others. By the adult stage, however, the specific growth-rates of all parts of the glabella are sensibly equal to that of the stalk.

Since the specific growth-rates of most parts of the glabella are equal at any time, it appears that in *D. olini* the shape of the glabella is governed by the various absolute growth-rates and their ratios, rather than by the specific growth-rates.

I am very grateful to Professor G. Regnéll for permission to examine the specimens, and to Dr. K. A. Kermack for advice on some statistical questions.

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An Isolated Occurrence of Igneous Rocks at Gorei in the Las Anod District of the Somaliland Protectorate[1]

By J. E. Mason

(PLATES XVIII and XIX)

Abstract

The quartz-syenite outcrop in the Las Anod District of the Somaliland Protectorate has been known for at least twenty-three years, but the true relationship between it and the overlying Cretaceous sediments has not been clearly resolved. Some geologists have said that the igneous rocks are overlain unconformably by the Cretaceous, whilst others have said that they intrude the Cretaceous. The present contribution brings forward field evidence to confirm the former view.

Introduction

THE Shilemadu Range is situated on the northern flank of the Nogal Plain in the Las Anod District, South-Eastern Somaliland. It forms an impressive south-west facing scarp feature capped by Lower Eocene Limestone, which overlooks and is separated from the Middle Eocene Anhydrite Series of the Nogal Plain by a normal fault. At Gorei, 47° 48′ E., 8° 58′ N., the Lower Eocene, Auradu Limestone is underlain by the Cretaceous, Nubian Sandstone (Text-fig. 1). On the lower slopes of the escarpment igneous rocks of syenitic composition outcrop and their true relationship with the overlying Nubian Sandstone has been in doubt for a number of years. The igneous rocks have been recorded in the past by oil geologists. Some have suggested that the Nubian Sandstone rests unconformably upon weathered Archaean igneous rocks. Others have said that the igneous rocks intrude the Nubian Sandstone and are probably late Cretaceous in age.

The writer has been fortunate enough to visit the area twice during the past two years and enough evidence has now been collected to confirm the suggestion that the Nubian Sandstone rests unconformably upon the igneous rocks, which are probably of Archaean Age.

Previous Work

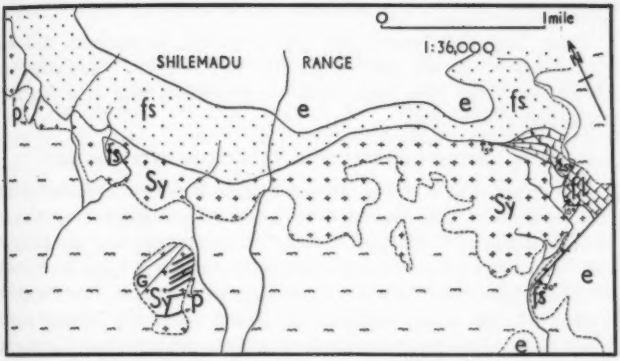
Macfadyen (1933, p. 35) described the small faulted outcrop of Archaean rocks seen at Gorei as a coarsely crystalline nordmarkite cut by a few dykes of quartz-porphyry and alaskite.

Macfadyen (1952, p. 59) mentioned this same outcrop again. He said that the field relations of the igneous rocks appeared to indicate intrusion through white Nubian Sandstone which was blackened,

[1] Published by permission of the Chief Geologist, Geological Survey, Somaliland Protectorate.

shattered, and slickensided at the junction. On this evidence he tentatively referred them, at least in part, to the Trap Series (Upper Cretaceous). He said that igneous pebbles (whose composition was not recorded) formed a bed at the base of the Nubian Sandstone and it was quite conceivable that the nordmarkite was of earlier date, only the quartz-porphyry, etc., belonging to the Trap Series. He said that this occurrence required further study in the field and otherwise.

Mackay (S.O.E.C., 1954, p. 18) mentioned that at Gorei Cretaceous sediments were affected by an intrusive mass of syenite which included



TEXT-FIG. 1.—Geological sketch map. Sy, quartz-syenite; P, porphyry and quartz-porphyry; G, granite; e, Auradu Limestone (Lower Eocene), Eocene); fs, Nubian Sandstone (Cretaceous); fl, Cretaceous Limestone.

dykes of quartz-feldspar-porphyry. At no point did the intrusion come into contact with the Lower Tertiary, although the syenite was found within a few metres of the base of the Auradu Limestone. He suggested that the intrusion was older than the Lower Tertiary.

IGNEOUS ROCKS

The dominant igneous rock type is a quartz-syenite. It is a brown weathering well jointed medium grained rock composed largely of interlocking tabular grains of potash feldspar. Quartz grains occupy the angular interstitial areas together with hornblende. The texture and composition of the quartz-syenite is variable. Quartz-rich segregations from 3 to 6 inches in diameter have been recorded. The quartz often exhibits a graphic intergrowth with feldspar and in this respect is comparable with some of the pegmatites of the Basement Complex. Towards the eastern end of the exposure the igneous rock is a mottled grey colour. Plagioclase is present almost in the same proportion as

the potash feldspar, and quartz is visible in the hand specimen. This rock which has been called an adamellite does not appear to be a separate intrusion, but a local variation of the quartz-syenite.

Minor intrusions of quartz-feldspar-porphyry and feldspar-porphyry with an approximate east to west and east-north-east to west-south-west trend are numerous. They rarely exceed 20 feet in thickness but one dyke of microgranite is 200 yards wide. Quartz-feldspar-porphyries are grey coloured rocks with an aphanitic, often banded matrix crowded with phenocrysts of pink lath-shaped orthoclase and equidimensional quartz. The feldspar-porphyries do not contain quartz phenocrysts.

From field observations the quartz-syenite, its variants, and the minor intrusions are mineralogically very similar. Although no chemical analyses have been made it is tentatively suggested that they are genetically related.

The Cretaceous Sediment, Quartz-syenite Contact

The upper surface of the igneous outcrop is very uneven but along the escarpment the contact with Nubian Sandstone maintains a constant level. On the lower slopes of the escarpment at the western end of the exposure, however, Nubian Sandstone is again in contact with the igneous rocks and at the eastern end, where the foothills occupy a larger area, limestones are found above the igneous rocks which are 400 feet lower than the level of the contact on the escarpment.

Immediately below the Nubian Sandstone the quartz-syenite maintains its medium grain size. There does not appear to be any change in the degree of crystallinity as the contact is approached. Similarly, the minor intrusions maintain a constant grain size and where the quartz-syenite is in contact with the Nubian Sandstone the intrusive dykes end abruptly. They do not appear to penetrate the sandstones to a higher level than the quartz-syenite.

In some instances fresh quartz-syenite is in contact with the Nubian sandstone but usually all the igneous rocks are decomposed to a varying depth below the contact up to a maximum of 25 feet. The majority of igneous rocks from this zone are white in colour due to decomposition of the feldspar and joint faces are usually iron stained.

Cretaceous Sediments

The Nubian Sandstone is of variable lithology. It is a current bedded, coarse grit often compacted to form a durable quartzite. Thin clay partings are not uncommon. At the base of the formation the lithology is variable. The dominant rock type is a conspicuous dark brown coarse ferruginous quartzite. In numerous exposures occasional pebbles of syenite and feldspar-porphyry are found in the

basal sandstones. Elsewhere arkosic grit bands containing feldspar and quartz crystals are not uncommon.

Towards the western end of the exposure a thick conglomerate is preserved. In this outcrop, which is situated towards the base of the escarpment, current-bedded Nubian Sandstone is banked against a cliff of weathered syenite. Beneath the current-bedded sandstones, blocks of syenite, which appear to have fallen from the cliff, are incorporated in sandstones with thin shaly partings (Plate XVIII, fig. 1). This horizon is underlain by a coarse well cemented conglomerate composed of rounded boulders and cobbles of weathered quartz-syenite, feldspar-porphyry, and quartz-feldspar-porphyry (Plate XVIII, fig. 2).

At the eastern end of the exposure Nubian Sandstones exposed on the face of the escarpment are underlain by limestones which thicken in a south-easterly direction (Plate XIX). They are thought to be Cretaceous in age. In the foothills and approximately 400 feet below the syenite-sandstone contact on the escarpment these limestones are underlain by weathered quartz-syenite. The lowest horizon is a massive dark grey fossiliferous porcellanous limestone crowded with feldspar laths which appear to have been derived from the underlying quartz-syenite. Irregular bodies of chalcedony with thin films of barytes developed on some surfaces are associated with this limestone. It is overlain by thinly bedded yellow-brown shelly and gritty limestones with sandstone partings, which pass upwards into more massive grey limestones.

Summary and Conclusions

At Gorei in the Shilemadu Range quartz-syenite intruded by dykes of quartz-feldspar-porphyry and feldspar-porphyry is in contact with Cretaceous sediments. The upper surface of the igneous rocks is usually weathered and nowhere do the dyke rocks penetrate the sediments to a higher level than the quartz-syenite. Both are terminated on the same plane which appears to be an erosion surface.

Boulders, cobbles, and pebbles of quartz-syenite are incorporated in the lowest sandstone horizons of the Cretaceous.

For these reasons it is suggested that the igneous rocks at Gorei did not intrude the Cretaceous but were part of the old land surface upon which the Cretaceous sediments were deposited. It is feasible that the igneous rocks represented an old shoreline during Cretaceous times, because plant remains are known to exist in the sandstones, the basal conglomerates would suggest a beach deposit and marine limestones were being formed in the same vicinity.

The age of the igneous rocks is not definitely known. The only other plutonic rocks of similar, but not identical, composition are

part of the Basement Complex, which is thought to be Archaean in age. It is tentatively suggested that the Gorei quartz-syenite and associated igneous rocks are members of the Basement System.

ACKNOWLEDGMENTS

The writer would like to thank the Chief Geologist, Mr. J. A. Hunt, O.B.E., for reading this paper, and J. McNinch, of the Conoco-Somal Oil Company, for his numerous discussions on the Gorei exposure.

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GEOLOGICAL SURVEY,
HARGEISA,
SOMALILAND PROTECTORATE.

EXPLANATION OF PLATES XVIII AND XIX

PLATE XVIII

FIG. 1.—This is the base of the Cretaceous exposed near the western end of the area. Here a coarse conglomerate is overlain by thinly bedded sands and clays in which angular blocks of quartz-syenite are embedded. These pass upwards into current-bedded ferruginous sandstones. The Cretaceous sediments at this locality are banked against a cliff of quartz-syenite which is to the left of the exposure photographed.

FIG. 2.—A view of the conglomerate seen in Fig. 1. Rounded boulders and cobbles of quartz-syenite and porphyry are the dominant constituents.

PLATE XIX

A view of the eastern end of the escarpment looking to the north-north-west. A ferruginous band towards the base of the Nubian Sandstone (fs) has been marked in. On the left it is separated from the quartz-syenite (Sy) by a thin bed of limestone (fl), which increases in thickness to the right and outcrops over most of the foreground, where it is partially obscured by rock debris.

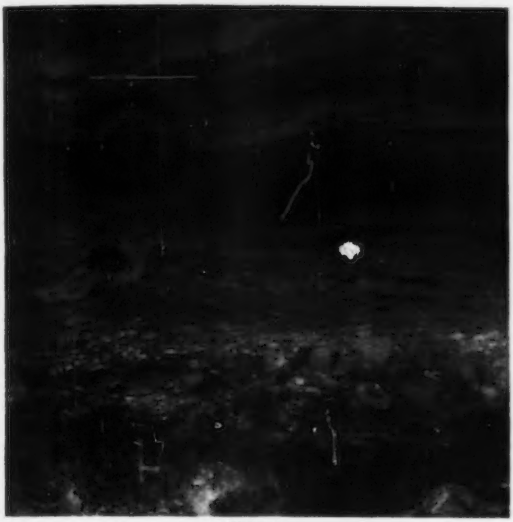


FIG. 1.

FIG. 2.

IGNEOUS ROCKS AT GOREI, SOMALILAND.

IGNEOUS ROCKS AT GOREI, SOMALILAND.

Diplograptus spinulosus sp. nov., from the Ordovician of Syria

By Margaret Sudbury

Abstract

Graptolites, found in Ordovician strata in a deep boring in northern Syria, are described as *Diplograptus spinulosus* Sudbury sp. nov.

Introduction

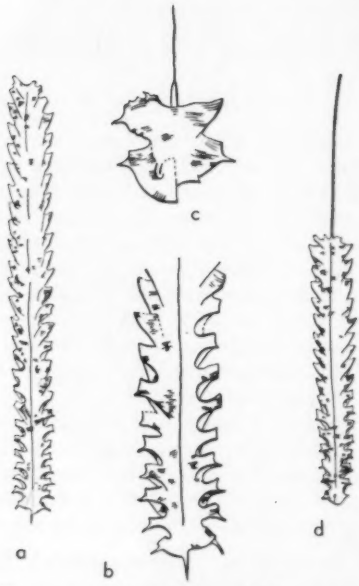
THE material described below was found in a deep boring put down at Abba, Syria (latitude 36° 20′, longitude 39° 21′) in 1948–49 by the Iraq Petroleum Company. The borehole passed through about 7,500 feet of Tertiary, Cretaceous, ? Jurassic and Triassic sediments before reaching beds (about 1,500 feet thick) which are probably largely Permian in age. Below these came a series of greyish-black thinly bedded micaceous shales with thin sandstone beds. This was found to be over 1,000 feet thick before drilling was stopped at 10,250 feet. Three cores taken in the lowest 100 feet produced the fauna described in this paper. All the fossils found have been presented to the Sedgwick Museum, Cambridge.

The graptolites described below occurred largely at a depth of 10,161–71 feet, but one or two specimens were found at 10,218–38 feet. In addition, trilobites, machaeridia, and brachiopods were found, the majority at a depth of 10,218–38 feet. Dr. C. J. Stubblefield identified the fossils listed below and gave an estimate of the age of the beds :—

Brachiopoda :	*Lingula* cf. *rugosa* Barrande (depth 10,218–28 feet).
	Lingula sp. (10,228–38 feet).
	Sowerbyella ? (10,218–28 feet).
Trilobita :	*Colpocoryphe arago* (Roualt) (10,218–38 feet).
	Pseudobasilicus cf. *nobilis* (Barrande) (10,161–71 feet, 10,228–38 feet).
	Fragments of Asaphid pleura (10,228–38 feet).
Machaeridia :	*Plumulites* sp. cf. *P. fraternus* Barrande (10,228–38 feet).
	Plumulites sp. (10,218–38 feet).

Only the trilobites give substantial evidence as to age. *Colpocoryphe arago* is best known in Bohemia, where it occurs in Llanvirn and Llandeilo strata. *Pseudobasilicus nobilis* is Caradoc–Ashgill in Bohemia, but has been recorded with *C. arago* in Spain (Born, 1918, pp. 313–4) where it is probably Llandeilo, and *P.* cf. *nobilis* has also been found in beds of Llandeilo age in Morocco (Termier, 1936, p. 1089). The Syrian strata are therefore tentatively assigned to the Llandeilo Series.

Other records of graptolites from the Middle East have come from the Hejaz (W. Arabia), where beds containing *Diplograptus* sp. were assigned to the U. Ordovician (Blanckenhorn, 1914, p. 14), and from S.E. Iran (Kuh-i-Furgun and Kuh-i-Gahkun, see Lees, 1938, p. 142,



TEXT-FIG. 1.—*Diplograptus spinulosus* sp. nov.
(*a*) Holotype, reverse side, × 2·5 approx. SM. A 46561*a*.
(*b*) Holotype, counterpart of 1*a*, obverse side, × 5 approx. SM. A 46561*b*.
(*c*) Fourth theca growth stage, obverse side, × 10 approx. SM. A 46565.
(*d*) Specimen showing nema, reverse side, × 2·5 approx. SM. A 46563*a*.

and Douglas, 1950, p. 4). The latter included *Diplograptus*, *Climacograptus*, and *Monograptus* and are therefore Silurian in age.

DESCRIPTION

Genus DIPLOGRAPTUS McCoy, 1850

Diplograptus spinulosus sp. nov. (*spinulosus*, L. = with a small spine).

Holotype : The specimen figured on Text-fig. 1*a*, *b*, from the Abba well core, depth 10,161–71 feet, SM. A.46561*a* and *b* (counterparts).

Other specimens: SM. A.46562–7, depth 10,161–71 feet; SM. A.46568, depth 10,218–28 feet; SM. A.46569, depth 10,228–38 feet.

Diagnosis.—*Diplograptus* with the thecal pairs 2 to 8–9 lasiograptid in form, each bearing a short spine, but with no lacinia. Distal thecae straight, about 9 in 10 mm. and rhabdosome about 2·5 mm. broad.

Description.—The longest rhabdosome seen is 38·5 mm. long; a shorter one (Text-fig. 1*d*) has a nema 10·5 mm. long at the distal end. The rhabdosome is 1·2–1·4 mm. broad at th1 and thence widens fairly slowly to 1·8–2·0 mm. at th5 and 2·3–2·5 mm. at th10. Thereafter the breadth remains constant. The first centimetre length contains eleven to twelve thecae and distally there are nine thecae in 10 mm.

The impression of the sicula can be faintly seen in the holotype. It is rather short, about 1·3 mm. long and 0·5 mm. broad at the aperture, with a stout virgella 0·5 mm. long.

Th1[1] is of a type which seems to be common to many Diplograptids: it has an evenly rounded base and a short stout spine just before the aperture. Th1[2] also bears a stout spine and is without a distinct geniculation (Text-fig. 1*c*). The succeeding proximal thecae resemble those of a *Lasiograptus*. Each free ventral wall is divided into two regions by a distinct geniculation. The distal part is straight and more or less parallel to the axis; the proximal part is concave and together with the apertural margin of the previous theca forms a semi-circular excavation which is deep and at least as long as the distal free ventral wall. There is a (?)single stout spine at the geniculation, but there is no lacinia and the periderm was probably complete.

This type of theca gives place rather suddenly to the distal type, the last fully lasiograptid pair being about th8 or th9. The distal ones consist of at first slightly sigmoidal, later completely straight tubes with an angle of inclination of 20–30°.

Overlap is very slight at the proximal end, but increases distally, certainly reaching about one-half at th25. A slight groove along the centre of the specimens seems to indicate the presence of a median septum, but it is quite straight and there is no sign of the zig-zag septum found in other Lasiograptids (Bulman, 1947, p. 72).

Remarks.—The form belongs to the genus *Diplograptus* s.str. since the proximal thecae are generally "amplexograptid" and the distal ones are straight. However, the deep wide excavations between the proximal thecae give them a short, squat appearance; this and the presence of spines invite comparison with *Lasiograptus* rather than *Amplexograptus*, since in the latter the thecae do not bear spines and the excavations are narrower. The absence of a lacinia and the complete periderm bring the form near to *L. retusus* Lapworth (1880, p. 175, see also Elles and Wood, 1908, p. 328) although the thecae in *spinulosus* are somewhat more widely spaced.

The distal part of the rhabdosome is fairly narrow for its length compared with many species of *Diplogratus* and in this respect is not unlike *Orthograptus truncatus* var. *intermedius* Elles and Wood (1907, p. 236). Both reach a width of 2·5 mm. rapidly and then remain parallel-sided, but var. *intermedius* has somewhat closer-set thecae, and of course, a different type of proximal theca.

Acknowledgments.—I should like to thank Dr. R. G. S. Hudson and Professor O. M. B. Bulman for their help and for allowing me to describe the above material; Dr. C. J. Stubblefield, for permission to incorporate his identifications and opinion as to age of the rocks in this paper; and the Chief Geologist, Iraq Petroleum Company, for permission to publish the results.

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Some Holothurian Spicules from the Upper Bathonian of the Dorset Coast

By JOHN S. HAMPTON

ABSTRACT

Six species (one new) of holothurian sclerites, representing the genera *Achistrum*, *Rhabdotites*, and *Etheridgella*, from the Upper Bathonian of the Dorset coast are figured and described, and are the first of such organisms to be recorded from the Great Oolite of England.

INTRODUCTION

ALTHOUGH several studies have been made of fossil forms occurring in British Jurassic strata (Hodson, Harris, and Lawson, 1956, p. 336), the present communication is the first record of holothurian remains from the English Bathonian. Samples were collected from the following coastal sections :—

Locality 1.—Watton Cliff, Dorset. About 1 mile south of Watton and $\frac{3}{4}$ mile north-west of West Bay (Nat. Grid Ref. 30/452908). Upper Bathonian, Forest Marble and Upper Fuller's Earth Clay.

Locality 2.—Herbury Point, Dorset. About $\frac{3}{4}$ mile west of West Fleet and 1 mile south of Langton Herring (Nat. Grid Ref. 30/611811). Upper Bathonian, *Goniorhynchia boueti* Bed and Upper Fuller's Earth Clay.

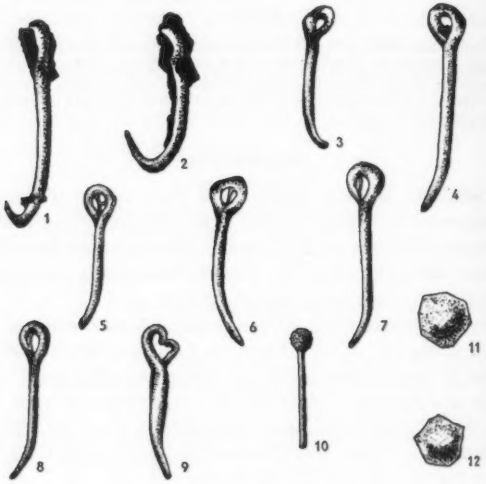
Holothurian remains occur throughout the 40 feet or so of Upper Bathonian rocks examined. In the Forest Marble and *G. boueti* Bed they are extremely rare, poorly preserved, and small, examples of the genera *Achistrum* and *Rhabdotites* being found. In the underlying Upper Fuller's Earth Clay, however, large and well-preserved spicules are not uncommon and, apart from a few plates referred to *Etheridgella*, are hooks confined to long ranging species of *Achistrum*. The absence of rotiform spicules may be due to the somewhat arenaceous character of the beds studied (op. cit., p. 337), the infilling of the terminal loop by matrix made the specific determination of several examples of *Achistrum* (Text-figs. 1 and 2) impossible.

The registration numbers prefixed with the symbol E, referred to in the text, are those of figured material deposited in the Department of Palaeontology, British Museum (Natural History).

I am indebted to Mr. S. J. McNicol, of the Department of Geology, University College, London, for allowing me to study the material he collected and prepared ; and to Dr. Frank Hodson, of the Department of Geology, The University, Reading, for helpful advice during the preparation of this paper.

Systematic Descriptions

The classification followed is that of Frizzell and Exline (1955), which is based on the morphological character of the sclerite, and is, therefore, completely artificial.



Text-figs. 1–12.

All figures approximately × 26.

1. *Achistrum* sp. ind. E.27033.
2. Ditto. Upper Fuller's Earth Clay, Herbury Point. E.27034.
3. *Achistrum* cf. *bathonianum* Frizzell and Exline. E.27035.
4. Ditto. E.27036.
5. *Achistrum gamma* Hodson, Harris and Lawson. E.27037.
6. *Achistrum monochordata* Hodson, Harris and Lawson. E.27038.
7. Ditto. E.27039.
8. Ditto. E.27040.
9. *Achistrum cordatum* sp. nov. Holotype. E.27041.
10. *Rhabdotites ?rectus* Frizzell and Exline. Forest Marble, Watton Cliff. E.27042.
11. *Etheridgella* sp. E.27043.
12. Ditto. E.27044.

Unless otherwise stated all figured material is from the Upper Fuller's Earth Clay of Watton Cliff. Originals of all figures are in Brit. Mus. (Nat. Hist.).

Achistridae Frizzell and Exline, 1955.

Achistrum Etheridge, 1881 ; *emend.* Frizzell and Exline, 1955.

Hodson *et al.* (1956, p. 339) recognize three well-defined subdivisions of this genus, based on the nature of the terminal loop, and Frizzell

(*in litt.*, 1957) suggests that they should be given subgeneric, if not generic, rank ; there appears to be, however, little justification for such a separation in the present study.

Group 1.—Terminal loop empty (Hodson, Harris, and Lawson, 1956).

Achistrum cf. *bathonianum* Frizzell and Exline. Text-figs. 3 and 4.

A. bathonianum Frizzell and Exline, 1955, p. 95, pl. 4, figs. 8–10.

Achistrum with a long thin shank and poorly developed spear, which in some specimens is absent (Text-fig. 4).

A. bathonianum to some extent resembles *A. issleri* (Croneis), but its terminal loop is not inclined, as in the latter species. The species is rather uncommon in the Upper Fuller's Earth Clay of Watton Cliff, and has not been observed elsewhere in the succession.

Group 111.—Terminal loop with a cross-bar (Hodson, Harris, and Lawson, 1956).

A. gamma Hodson, Harris, and Lawson. Text-fig. 5.

A. gamma Hodson, Harris, and Lawson, 1956, p. 340, text-figs. 12 and 13.

Achistrum with a markedly bifurcate cross-bar in the terminal loop.

This species, which was first described from the *Cardioceras cordatum* zone of the Oxford Clay at Redcliff, Dorset, is extremely rare in the Upper Bathonian, one specimen (E.27037) having been collected from the Upper Fuller's Earth Clay of Watton Cliff.

A. monochordata Hodson, Harris, and Lawson. Text-figs. 6–8.

A. monochordata Hodson, Harris, and Lawson, 1956, p. 340, text-figs. 10 and 11.

Achistrum with variably placed single cross-bar.

This very variable species is common throughout the Upper Fuller's Earth Clay of both localities.

A. cordatum sp. nov. Text-fig. 9.

Holotype : E.27041 (B.M.N.H.).

Sclerite in form of a hook ; shank wide, tapering, slightly arched, circular in cross section, no development of spear. Terminal loop replaced by two small incurved hook-like projections.

The single specimen, from the Upper Fuller's Earth Clay of Watton Cliff, is unlike any other form referred to *Achistrum* in lacking the terminal loop, but it is somewhat similar to the sigmoidal sclerites of the Recent holothurian *Sigmodota* (Cuénot, 1948, p. 87, text-fig. 108). which Frizzell and Exline (1955, p. 93) compare with the present genus,

STICHOPITIDAE Frizzell and Exline, 1955.

Rhabdotites Deflandre-Rigaud, 1952.

Rhabdotites ?rectus Frizzell and Exline. Text-fig. 10.

R. rectus Frizzell and Exline, 1955, p. 66, pl. 1, figs. 14 and 15.

Slender, broken rod, with a terminal pustule, of *Rhabdotites*.

The single specimen (E.27042), doubtfully referred to *R. rectus* Frizzell and Exline, described from the Triassic of St. Cassian (Southern Alps), was collected from the Forest Marble of Watton Cliff.

ETHERIDGELLIDAE Frizzell and Exline, 1955.

Etheridgella Croneis, 1932.

Etheridgella sp. Text-figs. 11 and 12.

Imperforate, concavo-convex, disks, with a poorly developed, raised pseudospire on the inflated surface, which in many specimens is absent. Irregular, subcircular to hexagonal outline.

The present species, which to some extent resembles *E. porosa* Croneis, described from the Pennsylvanian of Texas, is common throughout the succession at both localities.

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CORRESPONDENCE

THE PHYSIQUE OF WALES

SIR,—Under the above title Mr. E. H. Brown [1] recently discussed the physical features of Wales. The technique adopted in their study was based on the main on profiles drawn on topographic maps. This profile method was at one time very popular in America where I heard it described as a favourite device for keeping a class of geography students happily employed.

The main conclusion drawn from these studies was that the great plateau-like surface which extends from Central Wales towards the foot of the Brecon Beacons belongs to the same topographic feature as the surface of the South Wales Coalfield, exception being made of a part of the Brecon Beacons which was regarded as a monadnock (Figs. 1, 2).

This hypothesis is completely at variance with my assumption, made on several occasions, that the high plateau of Wales has been warped southwards from 1,700 feet south of Plynlimon to approximately 200 feet above sea level in South Pembrokeshire. It is fortunate that the relation of the surface of the South Wales Coalfield to that of the lower ground that surrounds it on at least three sides can be proved with certainty by geological evidence and this gives no support to Mr. Brown's hypothesis.

This geological evidence has been stated many times, but as its significance was apparently not appreciated by Mr. Brown nor by several distinguished geographers who took part in the discussion of Mr. Brown's paper, it is necessary to recall the salient facts.

Strahan described many years ago Triassic breccias near Llantrisant, west of Cardiff, which were banked up against the foot of an escarpment eroded in Coal Measures. From this locaility the escarpment rose sharply several hundred feet to the level of the rim of the coalfield.

To the south, an undulating plain known as the Vale of Glamorgan extends to the coast. The plain is floored mainly by Lias and Trias which rest unconformably upon Carboniferous Limestone, Old Red Sandstone, and Silurian rocks. The inliers of older rocks which project in places through the Mesozoic cover are almost obliterated relics of a one-time mountain area rising perhaps to 10,000 feet or more, which was elevated about the end of the Carboniferous.

The surface of erosion upon which the Mesozoic rocks rest was therefore fashioned during the New Red Sandstone period, or the interval of time between the end of the Carboniferous and the deposition of the local Trias (Keuper Marls). It was more or less a geological accident that the mountain area in the Vale of Glamorgan consisted mainly of Upper Palaeozoic rocks : elsewhere in Wales, as near Oswestry, Lower Palaeozoic rocks were undergoing erosion at that time.

Near Llantrisant the surface of erosion is sharply marked off from the surface of the highland which is the South Wales Coalfield by a conspicuous escarpment which can be traced for several miles, dividing in the main the Vale of Glamorgan from the coalfield area.

It does not need emphasizing that in view of the mode of origin of the surface of erosion there is no essential relation between its level and that of the highland area which was being eroded away.

During the New Red Sandstone certain rocks, especially limestones, became conspicuously red stained or raddled both inside the body of the rock and also along divisional planes. At Llanharan near Llantrisant it is probable that a large body of iron ore was formed at this time. Red staining or raddling extended in some places to many miles away from existing outcrops of Trias. It was formerly regarded as evidence of the former extension of the Trias much beyond its present boundaries. This is no longer believed and the phenomenon is attributed to the conditions of erosion in the New

[1] *Geogr. Journ.*, cxxiii, 1957, p. 208.

Red Sandstone, but the places where it occurs were not far from the surface of erosion at that time.

In North Wales it can be seen in the Carboniferous Limestone near Llanymynech, in Silurian mudstones on the Denbigh moors, and near Welshpool in Ordovician rocks. In South Pembrokeshire the nearness of the plateau surface to the New Red Sandstone erosion surface is proved by the occurrence in cavities in the Carboniferous Limestone of actual Triassic deposits.

The Forest of Dean is composed of Carboniferous and Old Red Sandstone rocks, but is separated by more than two miles from the nearest outcrop of Trias. The Carboniferous Limestones are in places strongly raddled and important bodies of iron ore occur in them. These are now attributed to the conditions of erosion that prevailed during the New Red Sandstone period. Although the Forest of Dean rises in one place to 1,003 ft. it must be regarded as part of an extensive plateau and it is only in limited areas that it rises above 750 feet. The plateau abuts westward against the great escarpment on the edge of the South Wales Coalfield.

Here again as near Llantrisant the escarpment marks a sharp distinction between the surface of the coalfield to the west and the surface of erosion at its foot.

This part of the great coalfield escarpment is continued into the finest escarpment in the British Isles which is topped by the Brecon Beacons. For anyone who has viewed this magnificent escarpment towering above the ground in front of it, it is impossible to regard seriously the claim now being made that the high ground behind it must be part of the same surface as the much lower ground at its foot.

This lower ground is that which rises gradually to Mynydd Eppynt and thence to the Central Wales plateau.

It is impossible to dissociate the Brecon Beacons escarpment from the escarpments east and south of the Coalfield, nor the plateau at its foot from the plateaux of the Forest of Dean and the Vale of Glamorgan. As these were clearly formed during the New Red Sandstone, they carry with them the implication that the northern escarpment and the plateau associated with it are of the same age and origin. As mentioned above there is independent geological evidence of this in many parts of Wales.

The hypothetical surface devised by Mr. Brown so as to comprise both the Central Wales plateau and the surface of the South Wales Coalfield is clearly a hybrid begotten of the improper association of two physiographic elements which have no essential feature in common. It is as if the present sea floor of Cardigan Bay is regarded as part of the same surface of erosion as the high land which extends back from the cliff top.

O. T. Jones.

Sedgwick Museum,
Cambridge.
19th November, 1957.

THE LIMESTONE-SHALE RHYTHM IN THE BRITISH LOWER LIAS

Sir,—The letter from Dr. Kent in the last number of the *Geological Magazine*, in which doubts are expressed about the primary origin of the Blue Lias limestones and shales, can be answered without difficulty. His first point, that many shales in the Midlands are fossiliferous like the limestones, appears to be due to a misunderstanding, partly owing to the brevity of my previous communication. In consequence a little amplification is necessary. The Dorset rocks can, following Dr. Lang, be classified into limestones, marls (grading into marly shales) and paper shales. The first two types are normally indistinguishable in fossil content and differ funda-

mentally from the generally barren paper shales which, as seen in thin section, are rich in carbonaceous matter arranged parallel to the bedding in fine laminae. The latter are indeed typical " euxinic " deposits. The shales to which Dr. Kent refers are the much more widespread marly shales. Paper shales are developed only at certain horizons and are far less conspicuous. It is reasonable to argue that if a primary origin can be proved in this way for certain beds the same should be assumed for those beds in which the evidence is indecisive.

In dealing with the next matter, viz. the considerable lateral extent of certain limestones, Dr. Kent acknowledges a rhythmic control of the original sedimentation and thus concedes what I regard as the fundamental point at issue. The main dispute then concerns the extent to which $CaCO_3$ might have segregated in the vertical sense, i.e. into bands of limestone, marl, and shale, to accentuate this primary rhythm. In this connection the specimens of *Lima gigantea*, with their " crazy " structures, prove nothing more than some diagenetic change, a matter already considered in regard to nodule formation. Far more important is the evidence of trace-fossils, such as *Chondrites*. Both Seilacher (1953) and Scott Simpson (1957) have emphasized that such structures can only be preserved if there is an original difference in the sediments, in this case $CaCO_3$ content. Insofar as subsequent $CaCO_3$ segregation causes any modification of the original patterns it is to obliterate them (this can be proved in the field). It is inconceivable that such delicate structures could be preserved so well if the limestones were formed subsequently in the manner envisaged by Dr. Kent.

It is agreed that unweathered limestones and shales are often not easily distinguishable. This is true not only of boreholes but of fresh sea cliff and quarry sections. Nevertheless the difference is marked enough, as can be proved by chemical analysis. It is dangerous, moreover, to argue that gradual transitions are unlikely to be produced by original sedimentary changes.

Space prohibits fuller consideration of these and related topics, but a detailed account will be published elsewhere.

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SEILACHER, A., 1953. Studien zur Palichnologie. I. Ueber die Methoden der Palichnologie. *Neues Jahrbuch Geol. u. Pal.*, 96, 421–52.

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A. HALLAM.

SEDGWICK MUSEUM,
CAMBRIDGE.
1st November, 1957.

SIR,—In his letter under this title in the September-October number of the *Geological Magazine* for 1957, Dr. Kent seeks to dismiss the evidence provided by *Chondrites* for the deposition of the Lower Lias limestones by normal sedimentation. It is true that one can imagine a mechanism whereby differences of texture in the sediment (such as might exist between the infilling of the *Chondrites* tunnels and the rest of the bed) are " developed " by differential carbonate segregation during diagenesis. I have proposed this mechanism to account for a type of preservation of *Chondrites* found in certain Lias nodules. But there is a big difference between this type of preservation and that of the mottled Lias marls and limestones.

And there is another difficulty about Dr. Kent's ideas. He thinks the presence of graded boundaries to the limestones is evidence in favour of their origin by post-depositional segregation. But if the *Chondrites* structure is essentially a product of such segregation then grading of composition might well be expected within it—and this is not the case. In fact, if the

varying shades of grey of *Chondrites* systems which penetrate one another (Simpson, 1957, p. 492) are to be explained by the varying reaction of slightly different sorts of sediment to calcite segregation, as Dr. Kent requires, then the gradual change from marl to limestone, or *vice versa*, with which the *Chondrites* colour changes are associated must also be due to an original difference in the sediment. Thus the lack of sharp boundaries to the limestone beds cannot be evidence of segregation, for it is primary in origin.

Surely the assumption that ordinary sedimentation may not involve graded junctions between limestone and marl is totally unwarranted; and it is difficult even to hold that graded junctions are to be expected with chemical segregation when in fact the concretionary calcareous nodules of the Lower Lias normally show much sharper boundaries than most of the limestones.

So far as I can discover the following summarizes the evidence which supporters of the segregation hypothesis can produce in their favour: (1) occasional fragmented *Plagiostoma* shells (indicating dilation), (2) thickening of limestone beds around large fossils, and (3) very rare cases in which the attitude of a fossil suggests that limestone surface and bedding surface may not be identical in some places.

I believe (1) and (2) are indeed evidence of segregation, but that such occurrences are confined to a few limestone beds which may be partly concretionary in origin or with which local concretionary centres are associated. The examples of (3) need to be interpreted individually and the evidence they provide at present cannot be claimed to be significant.

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SIMPSON, S., 1957. On the Trace-Fossil *Chondrites*. *Quart. Journ. Geol. Soc.*, cxii, 475–499.

S. SIMPSON.

GEOLOGY DEPARTMENT,
THE UNIVERSITY,
BRISTOL, 8.

6th November, 1957.

ASSOCIATION POUR L'ETUDE GEOLOGIQUE DES ZONES PROFONDES DE L'ECORCE TERRESTRE

SIR,—A field-meeting of the Association in the Scottish Highlands, in September, 1957, was attended by 19 members, representing the following countries: Belgium 3; France 4; Holland 1; Norway 1; Switzerland 2; United Kingdom 3; U.S.S.R. 4; West Germany 1.

From 13th–17th September the party was at Newtonmore, Inverness-shire, under the leadership of Professor J. G. C. Anderson, and studied the structure and high-grade metamorphism of Moinian and Dalradian metasediments and the associated migmatite and pegmatite complexes of Strathspey and Loch Laggan. Opportunity was also taken to see post-tectonic intrusions and glacial features.

The members then travelled via Inverness to Balmacara, Ross-shire, where from 17th–21st September, with Dr. J. Sutton and Dr. G. Wilson as leaders, they saw the Loch Alsh fold, the thrust-slices below the Moine Thrust and the folded Moine and Lewisian near Loch Carron and Loch Duich. Particular attention was paid to the successive sets of small structures, and the relations between these and the large folds and thrusts were demonstrated.

On 21st September the party sailed from Kyle of Lochalsh to Mallaig, thence by train to Fort William where the Ben Nevis Ring Complex was examined; the Parallel Roads of Glen Roy were also visited. After the main part of the excursion concluded on 24th September, some members spent a further few days in Ardnamurchan.

The Association was constituted at the Algiers Congress in 1952. The first field-meeting was held in Norway in 1955. It is proposed to hold the third meeting in 1958 in the Massif Central of France (Directors Professor M. Roques and Professor Lapadu-Hargues).

Information regarding the Association may be obtained from the Secretary, Professor P. Michot, Institut de Géologie Université de Liège, Liège, Belgium, or from the undersigned.

J. G. C. ANDERSON.

GEOLOGY DEPARTMENT,
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CARDIFF.

REVIEWS

SEDIMENTARY ROCKS. By F. J. PETTIJOHN. Second Edition, 1957, xvi + 718 pp., 119 tables, 173 figs., 40 plates. Harper and Brothers, New York. Price $12.00.

The author tells us that it has been necessary to rewrite, as well as revise, this book as a result of the large amount of literature which has appeared since the first edition was published. The first ten chapters follow the same general arrangement as in the earlier edition, each one being expanded and mostly rewritten. The chapter on shales, argillites, and siltstones, for example, is twice as big as its predecessor while that on classification and nomenclature is completely reorganized and rewritten. The latter part of the book has been rearranged, but covers essentially the same ground as in the first edition, with expansions and additions. A section on paleocurrents and dispersion, for example, refers to recent directional studies in the Cambrian of the Harlech Dome. A final new chapter deals briefly with the evidence bearing on the historical geology of sediments. The number of illustrations, of uniformly high quality, is increased and a welcome change is the rearrangement of the references (which were given as footnotes in the first edition) into groups at the end of the various sections and chapters.

W. W. B.

THE QUATERNARY ERA. By J. K. CHARLESWORTH. 2 vols., lxxviii + 1,700 pp. and 32 plates. Edward Arnold (Publishers), Ltd., 1957. Price 16 guineas.

Professor Charlesworth must be congratulated on writing this monumental work and the Editors on publishing it. A work of these dimensions must have been planned many years ago ; the mass of information collected over years of patient labour will be found to be a mine of information to all interested in this latest period of geological time. The main compensation to Professor Charlesworth for all this labour will be the knowledge that he has given students, teachers, and research workers a reference work in which they will find an epitome of all the papers which have appeared on this vast subject.

As Professor Charlesworth says in the preface, he has " endeavoured to give an objective presentation of the present position on the various Quaternary questions ". This he certainly has done ; moreover, he has covered practically the whole world in his survey, whether it be the views held by various Continental workers or the details of the stratigraphy of almost every land where records of Quaternary deposits are known.

The method adopted of giving all possible references at the end of each chapter makes for ease in finding the references, whilst at the end of Volume II there is a bibliography of 1,924 works, which is only a fraction of the works referred to in the chapter references. The value of this careful and extremely full documentation is that any reader can feel safe that he has not missed any important work if he has taken the trouble to look up all the references noted for the subject he is studying.

One of the disadvantages inherent in a work designed on these lines is that so many different opinions are given that many students on reading a chapter may ask themselves the question " what does Professor Charlesworth really believe himself about this problem ? ". In some cases he will find a short statement indicating which view the author favours, but in others he will be left to make his own deductions or assessments of the recorded facts.

Volume I, dealing with Glaciology and Glacial-geology, gives a full discussion of every aspect of these two subdivisions of the subject and will be found to be of the greatest value as a source of information. On most topics Professor Charlesworth takes the middle view ; he concludes, for

example, that glaciation remodelled rather than created the land-forms in areas formerly covered by ice.

As one example of the thoroughness of the work chapter xxvi, dealing with loess, may be mentioned. This chapter is thirty-five pages in length with a bibliography of 909 items at the end. It covers both North and South America, Europe, and Asia and discusses the theories concerning the origin of loess, its fauna, and age.

Volume II deals largely with the stratigraphy of the Quaternary. The succession of the glacial and inter-glacial deposits is examined, including their fauna, associated remains, and relics of early man and other relevant features, in both glacial and peri-glacial regions and in the pluvial belts. In time, as well as space, the analysis extends through the glacial period to the dissolution of the ice, with the resulting changes in the relative position of land and sea.

In the last chapter Professor Charlesworth deals with the views which have been put forward regarding the causes of the glacial period. Here, however, the only comfort that we get is that much more work needs to be done before we can hope to get a final solution to the problem.

The work on the whole must be viewed as an encyclopedia rather than as a book to read through. As such it is of great value and we must thank Professor Charlesworth for the vast labour he has put into it.

W. B. R. K.

THE ORIGIN OF THE AFRICAN FLORA: An Inaugural Lecture given at the University College of Rhodesia and Nyasaland. By A. S. BOUGHEY. 48 pp., with 6 figs. Oxford University Press, 1957. Price 4*s.* 6*d.*

The "flora" concerned is clearly defined in terms of vegetation types in primary Natural Areas, including only Africa south of the Sahara and discussing only flowering plants.

The author accepts completely "the most confident of the statements of the origin and development of the present continental masses", which is naturally that of Wegener and du Toit. His flowering plants are "probably" descended from pteridosperms (unspecified), from the "Temperate *Glossopteris* Flora" of Gondwanaland and in detail from two separate groups, ranunculoid and magnolioid, developing in different parts of the area (Gondwanaland). "By the close of the Permo-Carboniferous Glacial Period, it can be supposed that differentiating forms of Herbosae and Lignosae (Angiosperms) were established in the *Glossopteris* woodland of these two regions," etc., etc. Apparently the Recent genera *Cardamine*, *Nasturtium*, *Viola*, and others were established in the Permian and so on.

All this ingenious network of theory is given without a vestige of fossil evidence, and is based on Recent plant distribution patterns in Africa and the surrounding islands. Professor Boughey is not to blame for the scarcity of relevant fossils, but it is a pity that he chooses to lead young botanists even further away from geological facts. He just mentions microfossil evidence (p. 27), but makes no attempt to expand it to some definite system of working from the known (Recent) flora progressively backward through the Tertiary and Cretaceous to the unknown (Origin of Flowering Plants). Some of the necessary rocks and fossils are known to exist, and others are being discovered in borings; very much further work will need to be done but it can bear no possible relation to most of the theories in this paper.

N. F. H.

THE HISTORY OF THE BRITISH FLORA: A FACTUAL BASIS FOR PHYTOGEOGRAPHY. By H. GODWIN. 384 pp., with 26 pls. Cambridge University Press, 1956. Price 90*s.*

This historical account is confined to the Quaternary era covering interglacial as well as post-glacial periods; a short chapter gives a concise statement about Tertiary floral history with the conclusion that the

immediately pre-glacial flora " had a composition not far removed from that of the present day ". The author considers that one result of his extensive study is a reduction in interest in the possibility of local survival of plants in glaciated areas, leading perhaps to more concentration in future on peri-glacial areas.

The main part of the work is devoted to the detailed record of all known occurrences of vascular plants as macroscopic remains or as pollen, listed under species arranged in order of the *London Catalogue of British Plants*. Dr. Godwin has thus checked and incorporated the work of all previous authors such as Clement Reid and Mrs. Reid, with the large contribution from his own school ; the result which is his " factual basis for Phytogeography " must stand as an invaluable source of information for many years ahead.

Geologists working on the Quaternary may be disappointed that radiocarbon dating is covered by a very short section giving results only up to 1952 and indicating that some of these remain unsatisfactory. Palynology, on the other hand, is fully discussed from all points of view and this provides a valuable guide for the application of such work to the older geological systems.

N. F. H.

PRINCIPLES OF STRATIGRAPHY. By CARL O. DUNBAR and JOHN RODGERS, xiv + 356 pp., 123 figs., and 21 tables. John Wiley and Sons (Chapman and Hall), London, 1957. Price 80*s*.

One never knows exactly what to expect from a book called " Principles of . . . ". The word may mean fundamental methods or it may mean elements and the book may be an essay on scientific method or a manual of systematics. The present book contains an element of each ; it is partly devoted to a description of the sedimentary rocks and their interpretation in the light of modern sedimentation, partly to the fundamental concepts of stratigraphy.

The book is based on a course given by the authors at Yale, a course designed as an introduction to the systematic stratigraphy of North America. The first part is headed " Environments of Deposition " and deals with non-marine, marine, and mixed environments (sixty-four pages). Part two deals with " the basic stratigraphic relations ", comprising stratification, breaks in the record, and facies changes (thirty-eight pages). Part three is devoted to the description and interpretation of the common sedimentary rocks (eighty-six pages). The final part (fifty-one pages) is headed " Synthesis " and is concerned with the building up of the stratigraphical picture, from the local section to the system, with its attendant problems of correlation. The last section of this part is on the " Broad patterns in the distribution of sedimentary rocks ". The book has, therefore, a marked sedimentary bias, dealing with this aspect of the subject in an attractive, lucid manner and in varying detail. It is not, of course, a substitute for a standard textbook on sedimentary petrology.

In a broad subject like stratigraphy (interpreted in its fullest sense) there is room for a variety of approaches and the rapid growth in knowledge of modern sediments makes the sedimentary approach a particularly attractive and lively one at the present time. The underlying principle, of course, is that of uniformitarianism but this is neither expounded nor justified in the book.

The sedimentary approach can only proceed on the basis of succession building and correlation which makes up stratigraphy in its restricted sense and this is the other main concern of the authors. The section on correlation, of course, is the crux of the matter and will be read with interest by all stratigraphers. The authors define correlation as time equivalence, a relationship which cannot be directly determined, as can faunal and lithological equivalences. Correlation, therefore, is not objective ; it is essentially

an interpretation influenced by personal judgment. The various physical criteria of correlation are then described, including the use of key-beds, instrumental well logs, interdigitating facies, and radioactive dating. This is followed by the biological criteria, guide fossils, and their varying time and geographical ranges, evolutionary series, and fossil assemblages. (An introduction to the biological aspect is given earlier in the book in the section on facies changes where ecological factors and their effects on faunal distribution and succession are discussed.) Next comes " evaluation of criteria ", the solving of the three-dimensional jig-saw puzzle. Although the term is not actually used, the jig-saw analogy makes it plain that the inductive approach is the only permissible one, no single criterion being entirely dependable. An interesting final sub-section is headed " Conflicting Philosophies of Correlation ". This recounts the influence of Ulrich, with his conviction of the frequency and importance of unconformities and his relative neglect of facies changes, resulting in mistakes which have taken a long time to eradicate ; and of Grabau, who " stood for the other system of ideas " with emphasis on broad facies relationships, a concept derived from the European school of stratigraphy. This is a cautionary tale with a moral, though it must be said that the authors do not point it very definitely. When told merely that eight other geologists concluded that Ulrich, in a particular case, was wrong, the sceptical student might well inquire whether it is just a question of weight of numbers.

A balanced account of stratigraphical nomenclature and its basic assumptions and of sedimentary rock types in association with geosynclinal and related structures completes the book. This last section is refreshingly free from the many cumbersome and premature names which have appeared in recent years.

However admirable a book of this kind may be one is always tempted to suggest alterations of emphasis. Is it, for example, necessary to include so much purely descriptive matter on the sedimentary rocks ? Such topics as the crystal structure of the carbonates and the Wentworth and Atterberg scales are surely included in the standard texts and university courses on mineralogy and sedimentary petrology. Perhaps the balance of the book would have been improved if some of this material had been omitted and the palaeontological aspect expanded. In particular, the writer would have liked to see more detailed examples of correlations of varying degrees of precision with the palaeontological data on which they are based.

A final reflection concerns the teaching aspects of stratigraphy. Does the student grasp and appreciate a general discussion of fundamental methods most readily before, during, or after the course of systematic stratigraphy ? In the writer's view, relatively little is gained if such a discussion is presented to the student before he has learned a good deal of detailed stratigraphy or, better still, has tackled a problem in the field.

The book as a whole makes attractive reading and could be studied with profit by any British student.

W. W. B.

PUBLICATIONS RECEIVED

F. J. NORTH. *The Stones of Llandaff Cathedral.* pp. xvii + 122, with 10 text-figs. and 21 plates. University of Wales Press, Cardiff. 1957. Price 15*s.*

L. S. PALMER. *Man's Journey through Time* : A first step in Physical and Cultural Anthropochronology. pp. xv + 184, with frontispiece and 55 figs. Hutchinson and Co., London, 1957. Price 30*s.*

GEOLOGICAL SURVEY OF GREAT BRITAIN. *Geology of the Country around Sheffield* (One-inch geological sheet 101, New Series) by R. A. EDEN, I. P. STEVENSON, and WILFRID EDWARDS. *Mem. Geol. Survey Gt. Britain*, pp. ix + 238, with 30 text-figs. and 6 plates. H.M.S.O., 1957, Price 27*s.* 6*d.*

GEOLOGICAL SURVEY OF NEW ZEALAND. Pal. Bull. 27. *The Genus Pecten in New Zealand.* By C. A. FLEMING. 69 pp. with 13 text-figs. and 15 plates. Wellington, N.Z., 1957. Price 18*s.* (paper covers), 22*s.* 6*d.* (quarter cloth).

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NEW ZEALAND DEPT. SCI. AND INDUSTRIAL RESEARCH. *List of Publications* (to) 1956. 22 pp. No price.

SOUTHERN RHODESIA GEOLOGICAL SURVEY. Bull. 43. *The Geology of the Country between Belingwe and West Nicholson.* By B. G. WORST. 218 pp. with 4 text-figs. and 25 plates, folding map in colour. Salisbury, S. Rhodesia, 1956. No price.

COLONY OF FIJI ; GEOLOGICAL SURVEY SECTION. Annual Report for 1956. 8 pp. and map. Government Press, Suva, 1957. Price 1*s.* 6*d.*

The Cretaceous Gastropod Genus Biplica. By W. P. POPENOE. Univ. Calif. Publ. in Geol. Sciences, vol. 30, no. 6, 425–453, 2 pls. Univ. Calif. Press, 1957. Price $1.00.

Lower Tertiary Foraminifera from Contra Costa County, California. By B. Y. SMITH. Univ. Calif. Publ. in Geol. Sciences, vol. 32, no. 3, 127–240, 16 pls. Univ. Calif. Press, 1957. Price $2.50.

NOTICE

INTERNATIONAL PALAEONTOLOGICAL UNION

The International Palaeontological Union has hitherto functioned as a department of the International Geological Congresses, but at the 1956 Congress in Mexico it was decided to extend its activities, and it is now proposed to publish a Directory to the Palaeontologists of the World. The expanding interests of the Union have necessitated arranging a meeting previous to the next Geological Congress, planned for 1960 in Copenhagen, and the President of the Union (Dr. Maldonado-Koerdell, Mexico City) has decided to call a meeting to coincide with the XVth International Congress of Zoology, and the preceding Colloquium on Zoological Nomenclature, to be held in London during the period 9th to 23rd July. During this session the Union will discuss and adopt a revised Constitution, as modified from that first put forward in 1956 at Mexico. All interested palaeontologists are asked to write for further particulars to the Secretary : Dr. Jean Roger, Service d'Information géologique, B.R.G.G.M., 74 rue de la Fédération, Paris XVe.

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